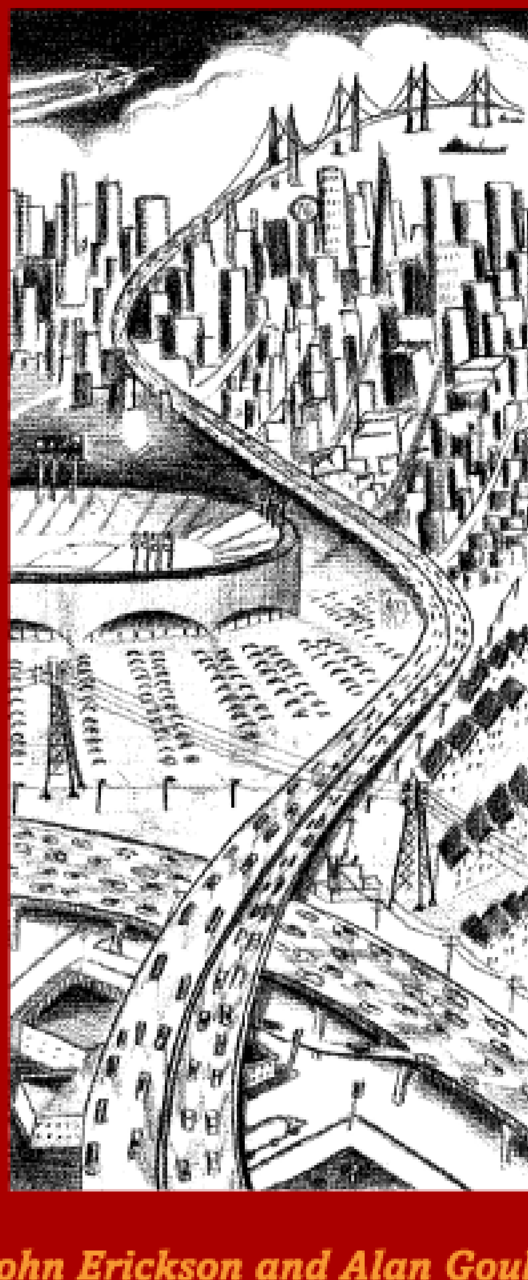
ENERGY USE



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Global Systems Science

http://www.lawrencehallofscience.org/gss

LHS

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Global Systems Science is an integrated, interdisciplinary course for schools, grades 9–12. GSS consists of twelve student books (see back cover), Hands on Universe Image Processing software, and Digital Earth Watch software. Each GSS book deals with societal issues that require science for full understanding. GSS may be used in designing an integrated interdisciplinary science course or serve as supplementary materials for existing biology, physics, chemistry, Earth science, or social studies courses. To obtain latest information about GSS books, please visit the GSS website:

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Global
Systems
Science

Energy Use

John Erickson and Alan Gould

Contents

News and updates are available at the GSS website http://www.lhs.berkeley.edu/GSS/ in the "Staying Up To Date" section.

Part I ***WHAT IS ENERGY?***

1. How People Use Energy

Without energy, nothing happens. *With* energy, things start happening. An intricate web of energy connects everything. The sound of rain on the leaves, the sound of a waterfall, and the sound of a rock concert are all related. Here's how . . .

The Sun shines on oceans, rivers, lakes, and sunbathers wet from a swim. Water, absorbing the Sun's energy, becomes vapor, and is carried by the wind. It returns to Earth as rain or snow. Some of it falls in sections of North America and drains through rivers and streams into the Great Lakes. Each minute 379,000 tons of this water tumbles over Niagara Falls, dropping more than 160 feet, accelerating by the force of gravity to nearly 70 mph. The energy of this tumbling mass is transformed to heat and tremendous noise as the water crashes below. Tunnels upstream from the falls divert some of the water through powerful water turbines which drive some of the largest electrical generators in the world. Electricity flows through wires to supply the energy needs of millions of people, including those enjoying the sounds from a band's amplifiers at a rock concert.

All living things need energy for growth, reproduction, survival, and comfort. In channelling energy, each species changes its environment. Changes can happen quickly, as when a beaver's dam turns a woodland valley into a pond. Changes

Niagara Falls

To the Iroquois, Niagara Falls was "Thunder Water." To daredevils it was a place to do stunts on tight-ropes and in barrels. Newlyweds still flock there for honeymoons. Nearby cities thrive on the tourist money. Today, much of the water is diverted to produce electricity; but the United States and Canada have agreed to keep enough water flowing over the falls to preserve the spectacle for tourists.

can be slower and more far-reaching, as when microbes on the shores of ancient oceans transformed our planet's atmosphere from suffocating gases into the oxygen-rich air that supports life today. Humans have the ability to rapidly and profoundly change the environment through their use of energy.

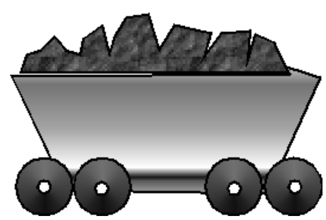
Our ways of channeling energy have important side effects. People who wash their clothes by the river bank and dry them in the Sun affect the environment differently from those who use electric washers and dryers. Thousands of morning commuters in cars affect the environment differently from people who go on foot.

The standard of living of industrialized nations is built on a use of energy many times higher than that of the non-industrialized world, and many times higher than at any other time in history. Side effects of this energy use include increases in air and water pollution, with associated health problems. Also, our current energy use produces large quantities of carbon dioxide which may bring about planet-wide climate changes from an increased greenhouse effect and global warming.

Energy Use Past and Present

Since the beginning of the Industrial Revolution more than 150 years ago, the ways people use energy have changed, and the pace of change has increased. We can easily divide the history of energy sources into three eras.

Wood Era. Before 1850, wood was the dominant energy source. Trees were plentiful and cutting them provided fuel and cleared the land for farming and development. Over the years, as more land was cleared, wood had to be transported farther, so it became expensive. Today, many people prefer not to use wood for fuel because it is costly and wood smoke affects air quality more than other fuels.



Coal Era. In the 19th century, as the forests disappeared, wood was used less and less because a cheaper fuel became available—coal. Coal has several advantages over wood. A trainload of coal provides a lot more energy than a train load of wood. New manufacturing processes and the invention of steam-powered trains demanded high temperatures that coal could easily provide. Mining technology made large quantities of coal available at lower prices.

Oil and Gas Era. Recently, oil and gas have replaced coal as the dominant energy source.

Question 1.1

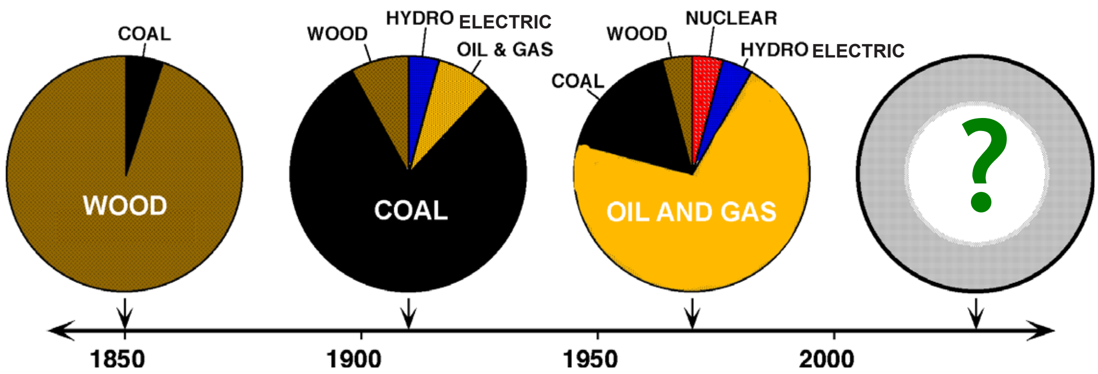
Can you think of any advantages that oil and gas have over coal that might account for the change?

Question 1.2

Any guesses what the pie chart on the next page will look like in the year 2030? How old will you be then?

Sources of Energy at Various Times During Recent History

Each pie chart shows the major sources of energy in the United States for the years 1850, 1910, and 1970.



Information is from the U. S. Bureau of Mines and Federal Energy Administration. Adapted from Global Science, *Christenson, Kendall/Hunt Publishing Company, 1991.*

Four "snapshots" of energy use patterns in recent U.S. history.

In the past few decades other energy sources, including nuclear and hydroelectric power have been added to the energy source pie. Hydroelectric power is the harnessing of the energy of rivers, such as at Niagara Falls. Nuclear power harnesses the energy stored within atoms. Nuclear power, aside from nuclear bombs, is used to generate electricity.

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/9eu.html. We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

Investigation

Recent History of Energy Use

"My grandfather used horses to plow his fields. The hay and oats that powered those horses were the source of energy. Now the same fields are plowed with tractors and we get our energy from gasoline."

"People did not just hop on an airplane back then. If it was more than a day's drive or more than overnight on a train, we just didn't go."

The memories of living people can show how rapidly energy use has changed in recent years. Even people 10 years older than you can probably tell you about new developments in energy use that have happened in their lifetimes.

Find someone to interview. It could be an older relative such as a parent, grandparent, aunt, or uncle. It could be someone unrelated to you. Just be sure it is someone you can trust not to tell you a tall tale. "When I was a lad we used to walk 20 miles to school in blinding snowstorms. Air conditioners? Why in summer we fried eggs on the kitchen table tops."

Topics to discuss during the interview that may help you find out about changing uses of energy are:

- Cooking
- Communication
- Transportation
- Heating
- Entertainment
- Business
- Vacations

Side Effects of Our Energy Use

Today, the average person uses far more energy than that person's grandparents used—and there are more people alive today than ever before. Since we rely mostly on oil, coal, and gas, our energy use generates serious problems, including the following.

- Pollution from burning fuel causes health problems.
- Carbon dioxide from burning fuel contributes to global warming which is likely to affect the world's climate system.
- The cost of fuel rises as it becomes scarcer, which can strain standards of living around the world as more money has to be devoted to pay for energy use.

Within your lifetime, the ways people use energy will have to change again, and you will help to make those choices.

We can help to limit our effects on the environment by learning how to use energy wisely. However, wisdom does not come from memorizing a few simple rules. There will be many choices related to energy use in the future—including some that we cannot even imagine today. In order to acquire the wisdom to make the right choices, it will be important to learn about how people use energy now. That's what this book is all about.

2. Energy Basics

In order to make intelligent choices about energy it's important to understand what energy is. Surprisingly, energy is not easy to define; and you are likely to find different definitions in different textbooks. A useful definition for ***energy*** is "that which makes things happen." Can you see energy? Actually, all you can see is energy, because light itself is energy. Our other senses (touch, hearing, taste, and smell) also depend on the interaction of energy with our bodies. Energy is a part of every moment of our experience. See if you can apply this definition in the following investigation.

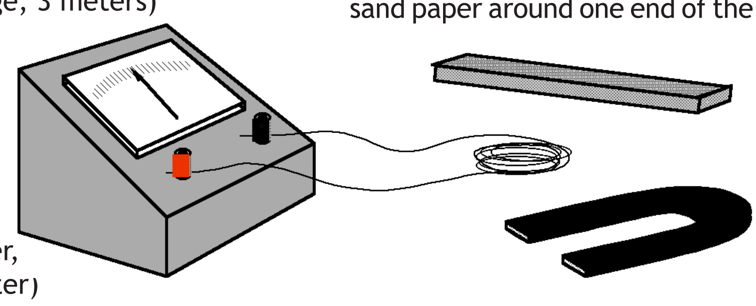
Investigation

Doing Work to Create Electricity

Use magnets and coils of wire to investigate what kind of responses you can get from an electric meter. Your challenge is to arrange and rearrange the magnets and wires to generate as much electrical output as you can.

Materials

- magnet wire (24 gauge, 3 meters)
- wire clippers
- sand paper
- iron rods
- magnets
- electric meter (can be galvanometer, volt meter or ammeter)



Preparation

1. Cut a length of magnet wire about 3 meters long. Typical electric wire has a plastic insulation that can be stripped off at the ends so that you can make electrical connections. Magnet wire has a lacquer insulation on it that can be removed with sand paper. Fold a small piece of sand paper around one end of the magnet wire. Pinch it firmly with one hand and pull the wire out with the other hand. Repeat this until the shiny pink copper is completely uncovered. Strip about 3 centimeters off both ends of the wire.

2. Make a coil with your wire. Your team must make these decisions:

- How many turns of wire will the coil have? You are limited by the length of the wire.
- How large will the coil be? This decision may be influenced by the size and shape of the iron rods and the magnets that are available to you.
- Will you wrap the coil around one or more iron rods, or will your coil have an open core? To make an open-core coil, wrap the wire around your fingers (loosely!), or another object, and then remove the coiled wire.
- Leave at least 20 centimeters of wire at each end of the coil.

3. Connect the ends of the coil to the electric meter. The meter may be a galvanometer, a volt meter, or an ammeter

Strategies for Investigation

1. Move the coil and the magnet near each other. Watch the needle on the meter. Movement of the needle indicates that electricity is flowing through the coil. Try different ways of moving the coil to produce as much electricity (movement of the needle) as possible. What happens when the coil stops moving?
2. Sketch the arrangement of the coil and the magnet. Note where the poles of the magnet are and indicate how they were moving when the meter responded. If your meter can indicate the direction of the current or whether the voltage was positive or negative, then note how that changed as you moved the magnet and coil.
3. Share what worked and what did not work with other groups in your class. Then try to increase the electric output of your system. Decide with your team on one change to make in your coil or a change in the way you moved your coil and magnet. Rebuild your coil and repeat the procedure to see if the meter responds differently. Record your results and make a new sketch of your rebuilt system.

Results

Make a brief report on your generating system that includes all the sketches and meter readings. Make sure your report answers these questions:

1. What kind of motions did you make with the coil and the magnet that caused the highest readings on the meter?
2. If your meter sometimes gave a positive reading and sometimes a negative reading, that means the current changed the direction it was flowing through the wire. Were you able to control which way the current flowed?
3. How did the changes you made in the system during the experiment affect the electric output?
4. Recall the definition of energy, where can you find energy in the system consisting of you, the coil of wire, the meter, and the magnet?

Converting Motion Energy to Electrical Energy

A number of different answers are possible for where you can find energy in the system consisting of you, the coil, meter, and magnet. Certainly there is energy in the movement of your hand. There must also be energy in the coil while it is being moved near the magnet, because it makes the needle in the meter move.

In 1831, Michael Faraday connected a loop of wire to an electric meter. He noticed that the pointer on the electric meter jumped when he moved the coil of wire near a magnet, just as yours did in the previous activity. This discovery led to the invention of the electric generator, which produces nearly all of the electricity that lights our cities and powers modern industry.

What happens inside the coil of wire when you move it near the magnet? One way to think about what is happening is to visualize tiny particles—called ***electrons***—that are free to move through the coil of wire. The electrons are pushed and pulled by the magnet. When these electrons move in the wire, they cause the needle in the meter to move. The flow of electrons through the wire is electrical energy, or simply ***electricity***.

Notice that neither the magnet nor the coil *alone* can produce electrical energy—it takes the movement of the coil by your hand to produce the electrical energy. Motion energy is called ***kinetic energy***. In the previous activity you converted kinetic energy into electrical energy.

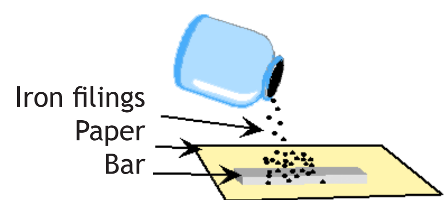
Let's look inside an electric generator and see how it converts kinetic energy to useful electrical energy. Keep in mind that although it looks complicated, an electrical generator works on the same principle as the system you already explored—you, the coil, meter, and magnet.

Energy of motion = kinetic energy. Image courtesy of www.wikipedia.org

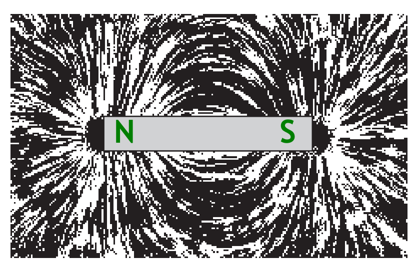
Inside an Electric Generator

Magnets turn up often in modern life. You find them stuck to refrigerators, in telephones, televisions, motors, speakers, recording tape, credit cards, and bank cards. Magnets seem to act like magic. All magnets have *North and South poles* that attract each other, but South poles repel South poles, and North poles repel North poles.

Scientists use the concept of a *field* to describe the force a magnet can exert in the space surrounding it. A magnetic field is invisible, but flakes of iron around a magnet will line up to show the direction of the field lines.



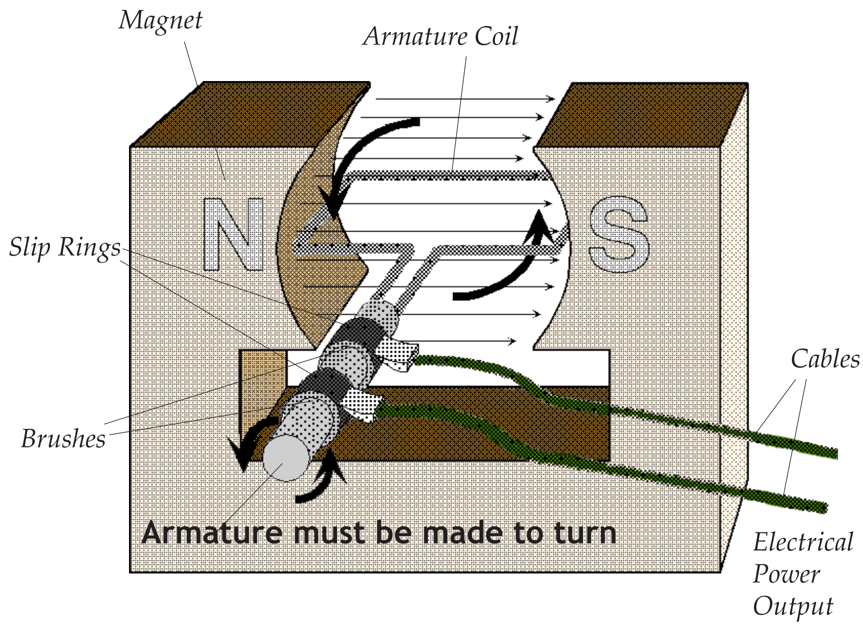
When you pour iron filings on a piece of paper over a bar magnet, you can see the pattern of the magnet's magnetic field.



Field of a Bar Magnet

An Electric Generator

It transforms mechanical energy to electrical energy



You may be familiar with a small electric generator used on bicycles to power a light. The generator is attached to the bicycle so that peddling turns not only the bicycle wheel, but also turns a coil of wire inside of a magnet. The work of peddling the bike produces the electricity to power the light. Here's how it works.

Inside the generator, a magnet creates a strong magnetic field. A coil of wire called the *armature coil* spins in the magnetic field. As the wire moves through the field, the electrons in the wire are forced around the coil by the magnetic field. During one half of a turn the electrons are pushed one way and during the other half of the turn the electrons are pushed the other way. This pushing of electrons is how the generator produces electricity.

In order to get electrical power from the generator, the armature coil must be connected to cables. There is one small difficulty. The armature is always turning. If the cables were connected directly to the armature coil they would get twisted very quickly. Instead, the wires at the ends of the coil are connected to *slip rings* on the shaft of the armature. The cables that carry current from the generator are connected to *brushes* that rub against the slip rings as the armature turns. Can you find the slip rings and brushes on the diagram on this page?

Question 2.1 Why is it important that the power to run the exciter coils be less than the power the generator produces?

The diagram of "An Electric Generator" is simplified to show the principles of a generator. Here are some ways a real generator is different from the one in the diagram.

- The diagram shows a single loop of wire in the armature coil. In the coil of a real generator the wire is wrapped around many times.
- The armature coil in a real generator is also wrapped around a core of iron to intensify the magnetic field.
- The armatures of most large generators have more than one coil, each one in a different position. That way one generator can act as several separate sources of electrical power.
- The magnet in a large generator is an electromagnet. It consists of coils of wire, called *exciter coils*, to create a large magnet and the large magnetic field.

Investigation

Using Electricity to Do Work

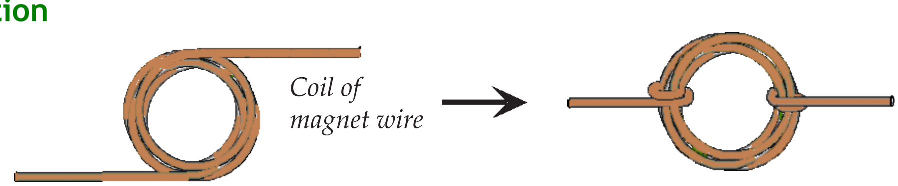
In the Lab Investigation "Doing Work to Create Electricity," you were generating electricity by moving a coil of wire near a magnet or moving the magnet near the coil. The generator transforms kinetic energy (energy of motion) into electrical energy. Do you think you can make it work in reverse: force a coil to move by putting electricity into it? That's what an electric motor is! It transforms electrical energy into kinetic energy. See if you can make an electric motor with the same parts you used before, with the addition of a battery, some paper clips, and thumb tacks.

Materials

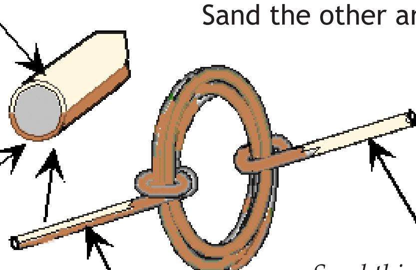
2 thumb tacks	soft wood block (3" square x $^1/_2$" deep)
2 paper clips	wood dowel ($^3/_4$" x 2" long)
magnet	magnet wire (about 50 cm)
6-volt battery	2 connecting wires

Strategies for Investigation

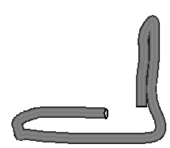
1. Wrap the magnet wire around a dowel about 15 turns leaving about 5 cm of wire on either end. Wrap each end around the coil two or three turns to hold it together.



2. The copper wire has an enamel coating, and must be sanded to allow for an electrical connection. Sand **one** arm **completely around** on all the sides.
   Sand the other arm **only** on the top.



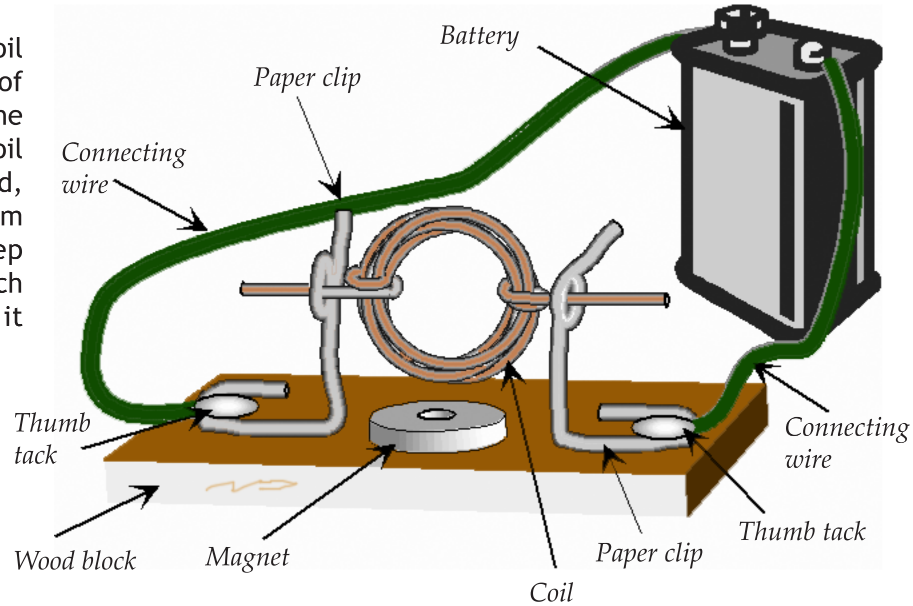
3. Bend each paper clip into a 90° angle. Notice that there is a longer side and a shorter side.



4. Bend the open arm of the larger side up to make a loop.

5. On the wood block, place the thumb tacks and paper clips as show in the "Electric Motor" drawing on the next page.

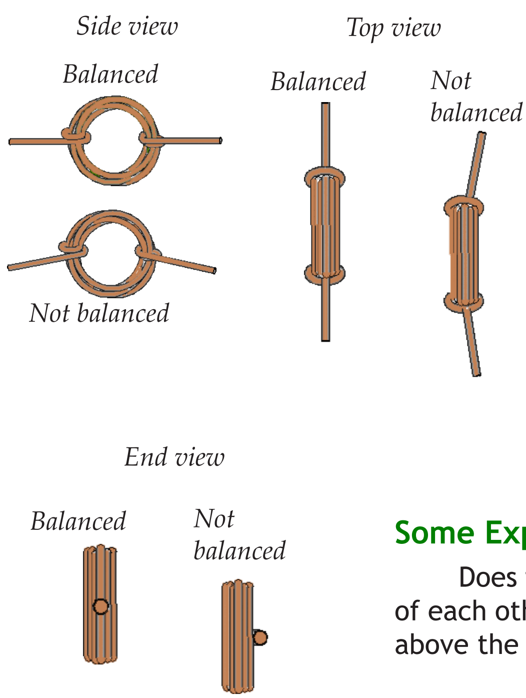
6. Place the arms of the coil through the little loops of the paper clips. Adjust the coil's arms so that the coil is centered and balanced, as shown on the bottom half of this page. Keep spinning the coil after each little adjustment until it spins freely.



7. When the coil is balanced, place the magnet underneath it between the paper clips. Attach a connecting wire to each battery terminal and then to each paper clip at the thumb tacks. Give the coil a spin, and watch it go!

If the motor does not work, here are a few things to check.

1) Make sure the coil's arms are sanded where they touch the paper clips.
2) Make sure the coil is properly balanced.
3) Is the battery good?
4) Check all connections.



Explanation

The motor is like a generator in reverse. Putting a current of electricity through the coil of wire makes it magnetic and it's magnetic field pushes against the magnet under the coil, making the coil flip over. The arm of the coil sanded on one side only is called the *commutator*. The insulated side turns off the magnetism in the coil for half the turn, allowing the coil's momentum to flip it around until the poles can repel each other again. The process continues, and the coil will keep flipping as long as the battery is connected.

Some Experiments to Try

Does the motor run faster if two magnets are placed on top of each other underneath the coil? How about with one magnet above the coil and one below?

Avoiding Confusion

We use a lot of energy-related terms in everyday language. That sometimes makes it difficult to understand the precise way these words are used in science. For example, compare the meaning of the terms **work** and **power** in these two sentences. What is the different meaning of the word in each case?

(1) Leonardo's painting "Mona Lisa" is such a magnificent **work** it has the **power** to move people to tears.

(2) The **work** of peddling the bike produces electricity to **power** a light.

In sentence (1) we can figure out what the terms "work" and "power" mean from the context. In sentence (2) the same terms have the following specific meanings:

Work refers to the amount of energy expended when a force is exerted for a certain distance. For example, twice as much work is done if you peddle your bike twice as far. Twice as much work is also done if you push twice as hard on the peddles for the same certain distance.

Power is the speed, or rate, at which energy is converted from one form to another. A ten-watt bulb in your bicycle headlight converts electricity into light energy twice as fast as a five-watt bulb. It is therefore important not to put too high a wattage bulb into your headlight, which will require more electricity to stay lit than a lower wattage bulb, so you don't have to work so hard to keep it lit.

Energy is defined in this book as that which makes things happen. Work is a kind of energy; so is light and electricity.

Kinetic energy is energy of motion.

Potential Energy is one more kind of energy you need to know. Potential is another word that has different meanings in everyday language. We can talk about someone's potential—meaning what they could achieve. In science, *potential energy* is stored energy. There are many different kinds of potential energy. When you pick up a stone you are increasing its potential (gravitational) energy. Let go and it turns into kinetic energy as it falls. Batteries hold potential chemical energy. Connect the terminals of a battery with a wire and light bulb—you turn some of the battery's potential (chemical) energy into heat and light energy. In the next activity you'll turn potential chemical energy into kinetic energy.

AC/DC

When you measure the current from a battery, the reading on the meter remains steady. Electrons flow in one direction through the wires pushed by a steady force. That kind of current is called *direct current* or *DC*.

In the Lab Investigation "Doing Work to Create Electricity," when you moved the wire in the field of a magnet, its position was changing and the current was rising and falling, or even reversing direction. Producing DC with magnetism is a tricky job, but it is fairly simple to use magnetism to generate a current that alternates back and forth in a regular way. This is called *alternating current*, or *AC*.

In an AC power system the electrons do not flow very far before they stop and flow the opposite way. Electric power from a standard outlet is AC in which the current reverses direction 60 times per second.

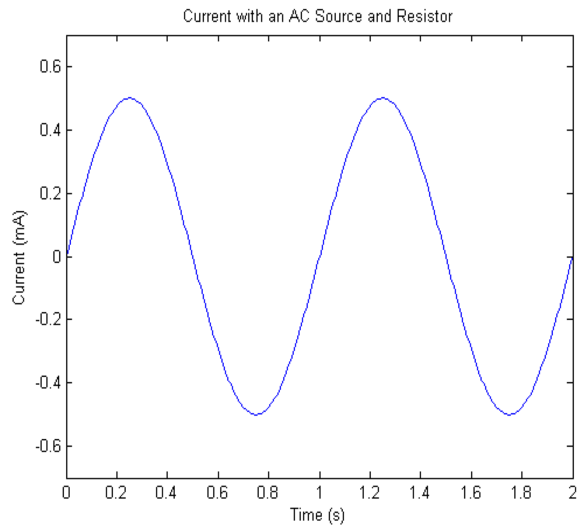


Image courtesy of www.wikipedia.org

Conservation of Energy

Energy is never created or destroyed. When a battery runs down, people speak of energy being "used up," but "used up" energy has not disappeared. It has been converted from one form of energy to another. This is called the *Law of Conservation of Energy.* This is one of the most important ideas in physics, and we will see it again later in this book.

Conclusion

When we use energy for our own purposes, we are really transforming energy from one form to another. If we trace back these energy transformations to their sources, we find nearly all the energy people use to heat and light their homes, to run their cars, or produce the billions of products we use everyday, comes from stored chemical energy—energy stored in the ground for millions of years. We'll learn about these sources of energy, called "fossil fuels," in the next chapter.

Investigation

Energy Transformations

One of the major points of this chapter is that energy can take many different forms. Everyday we encounter situations in which one form of energy is being transformed into another form of energy. Consider this sequence of energy transformations. Energy arrives on Earth in the form of sunlight. This *light energy* is converted to *heat energy* as it warms up water. The heat causes evaporation and the water is lifted up into the atmosphere. When the water is lifted into the air it gains *potential gravitational energy*. When it comes down, that energy is converted to *kinetic energy* of billions of individual raindrops. Those raindrops may join the river that flows over Niagara Falls. Some of the kinetic energy of the water falling over the falls is converted to *electrical energy* in huge generators. The electrical energy produced by the generators power the lights (giving off *light and heat energy*) some newlyweds use to see and eat their dinner. As the newlyweds admire the falls during their honeymoon they are busy converting *potential chemical energy* from food from their dinner into thoughts *(chemical energy)*, physical movement (*kinetic energy*), and body warmth *(heat energy)*.

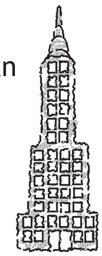
These are the forms of energy we have mentioned so far:

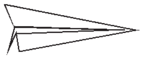
Heat Energy	Gravitational Energy	Electrical Energy
Light Energy	Chemical Energy	Potential Energy
Kinetic Energy	Nuclear Energy	

For each transformation, write down what form of energy it is and what form of energy it becomes.

1. A skateboarder rolls down a hill.
2. A car fills up at a gas station and drives across country.

3. An electric guitarist plays a D-flat minor chord at a rock concert.
4. A group of people go to the top of the Empire State Building in an elevator.

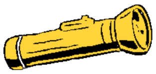




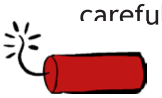
5. A girl throws a paper airplane.
6. A kettle of water boils and whistles on a gas stove.

7. A hydrogen bomb explodes.

8. A fan runs on batteries.



9. A flashlight shines down a dark tunnel.
10. A building is demolished with carefully placed sticks of dynamite.



Try making up a few of your own energy transformation "action sentences" and challenge your fellow students to identify which form of energy changes into which other form of energy.

Image courtesy of wikipedia.org

Energy and Work

It was probably the work of human slaves that lifted the huge stones to build the great pyramids in Egypt. The work that lifts a concrete slab to the top of a modern skyscraper may be done more humanely by a gasoline-powered crane, but it involves the same scientific principle: ***Work*** is the product of ***force*** times ***distance***. If we use the symbols **F** for force, **D** for distance, and **W** for work. The equation is:

W = F x D

To see how this equation is applied, imagine a stalled car and you are trying to push it to the side of the road. The harder you push—the more *force* you exert—the more work you do. The further you push the car—the greater the *distance* the car moves—the more work you do. Oddly enough, however, if the car is too heavy, and no matter how hard you push you cannot get it to budge, the work done will be zero (W = F x 0 = 0).

In the case of a crane lifting a concrete slab, energy from the gasoline in the crane's engine is transformed into *potential* (stored) energy of the concrete slab suspended at a great height. Should the cable break, the potential energy would be converted to *kinetic* energy (motion) as the slab speeds toward the frightened workers below.

Question 2.2
What force would be doing the work on the slab as it falls?

How is energy related to work? Remember, energy is "that which makes things happen." Another common definition:

"Energy is the ability to do work."

Again, consider the stalled car. If you don't have enough chemical energy stored in your body to get the car moving, you could ask a passing truck to use its kinetic energy to do the work needed to get the car to the side of the road.

A common unit of force is "pound." You have to exert five times as much force to lift a five-pound object as a one-pound object. In science, the most common unit of force is the *newton*, in honor of Sir Isaac Newton who made important discoveries about gravity in the 17th century. One newton is equivalent to a force of about .22 pounds.

Sample Problem

How much work does it take to lift a book from the floor to a shelf at a height of two meters, if the book weighs the equivalent of 0.25 newtons? Solution:

W = F x D   F = 0.25 newtons

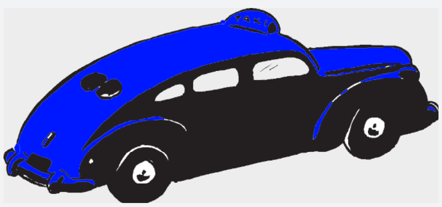
D = 2 meters

W = (0.25 newtons) x (2 meters)

= 0.5 newton-meter = 0.5 joule

In the formula for work, if force F is in newtons and distance D is in meters, then the units of work W is in "newton-meters." A newton-meter is also called a joule, named after James Prescott Joule, who was the first to show experimentally that work could be transformed into heat energy, and visa versa.

Work is done when an engine moves a car. Work is done when the brakes stop the car. Work is done when electrons are pushed through the filament of a light bulb. Is reading this page work? Well, you could say "No," since there is no force applied and the book remains stationary. On the other hand, reading and thinking *do* involve work since they cause electrons to move in our brains.



2.3 If 1 newton = .22 pounds, what is your weight in newtons?

2.4 How much work does it take for a newlywed husband to lift his bride one meter to carry her over the threshold of their new home, if the bride weights 500 newtons?

2.5 If an automobile has expended an amount of energy equivalent to 1,200,000 joules of work, and to propel the car the engine is exerting a force of 600 newtons, how far has the automobile traveled?

The Nature of Electricity

Static Electricity

More than 2,000 years ago, the Greek philosopher Thales (624-546 BC) wrote of how the substance amber attracted light objects when he rubbed it. William Gilbert (1544–1603) discovered that a variety of other substances did the same thing. He called these substances "electrics," from the Greek word for amber, *elektron*.

Have you ever rubbed a balloon on your hair so that it would stick to things? If so, you were giving the balloon an electric charge. There are two opposite types of electric charge called *positive* and *negative*. Most matter is made of particles with positive and negative charges in equal amounts. Equal amounts of positive and negative charge give a total charge of zero.

When you rub a balloon on your hair, particles that have a negative charge move from your hair to the balloon, and the balance of charge is no longer zero. The balloon is now negatively charged. What about your hair? What kind of charge does it have?

Benjamin Franklin (1706–1790) was the first to apply the words "positive" and "negative" to electricity. His work was mainly in the area of *static electricity*, the properties of charges that are not moving. Static electric forces follow these rules: positive charges repel each other, negative charges repel each other, and positive and negative charges attract each other. Electric force ranks as one of the basic forces in the universe, along with gravity and nuclear forces.

Atoms and Their Charged Ingredients

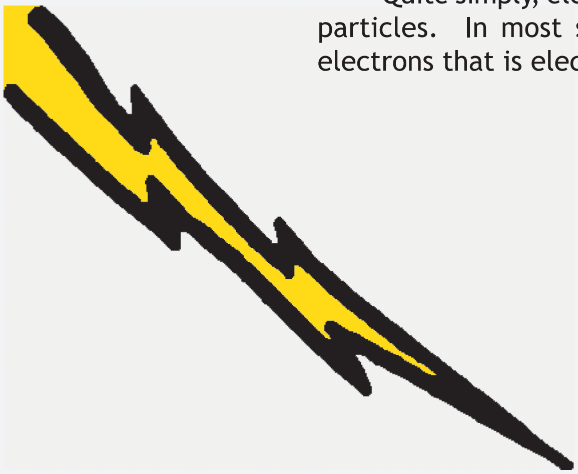
Soon after the time of Thales, the idea arose that if you cut a chunk of matter into smaller and smaller pieces you would reach a point where the pieces could no longer be cut. Their word for such a small particle was *atom*, meaning "cannot be cut." Today, the word "atom" is still used for the smallest building blocks of elements, but atoms are made of even smaller pieces—*protons*, *neutrons*, and *electrons*.

Particle	***Charge***
Proton	*Positive(+)*
Electron	*Negative (-)*
Neutron	*No charge*

Protons and electrons have equal and opposite charges, protons being positively charged and electrons being negatively charged. Neutrons have no electric charge. In each atom, the nucleus is made of protons and neutrons, and is fixed in a certain position. Electrons are far lighter than protons and neutrons. They surround the nucleus and can be pushed around more easily.

So What Is Electricity?

Quite simply, electricity is the movement of charged particles. In most solids, it is the movement of the electrons that is electric current.



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Part II ENERGY SOURCES

3. Fossil Fuels

Next time you look at a blade of grass, think about this: without green plants none of us would survive. In some cases, we eat plants directly to get the energy that is stored in them. In other cases, cows or pigs eat the plants, store the energy in their own tissue, and we get energy from them. In the end, all the fuel we burn to satisfy our bodies' energy needs come from green plants.

And where do green plants get the energy to produce food? The short answer is from the Sun. Sunshine brings energy to our planet at the rate of 178 million billion watts. About 0.06% of that energy falls on green plants, driving the process of photosynthesis, which converts the radiant energy of the Sun to the chemical energy stored in sugar molecules.

In addition to fuel for our bodies, we also need fuel for heat, light, and transportation. What have people throughout history burned for fuel? Anything they could find! Before 1750 the prevalent fuel was wood. Where wood was hard to find or too precious as a building material, people burned the stubble left after harvest, bricks of dried peat, or even dried dung. All of these fuel choices come from materials that were once alive.

When living material dies, its energy is usually released through slow decay or passed along through the food chain to other living things. Occasionally, geological processes intervene. Silt may cover a swamp, trapping the energy of plants and animals beneath the ground. As the Earth's surface shifts and buckles, pressure builds up on the organic material trapped in the crust. After a few hundred million years these once-living materials turn into coal, oil, or natural gas—the *fossil fuels*.

The fossil fuel age began in the second half of the 19th century, and continues to this day.

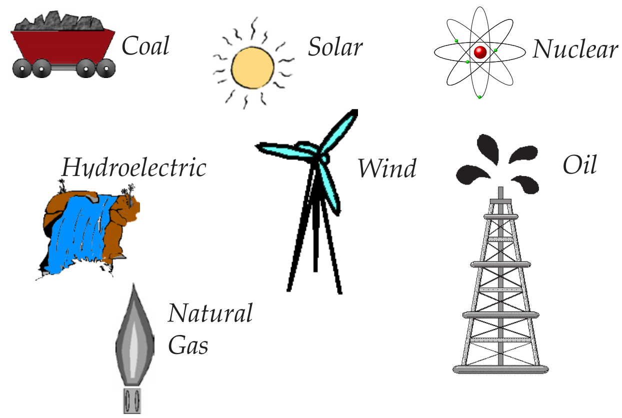
Oil pump. *The energy beneath the semi-arid surface is evidence of an environment that was once rich with life. Photo courtesy Los Padres Forest Watch.*

What Are Fossil Fuels?

There is no single explanation of how fossil fuels form. In general, the remains of plants and animals were prevented from decaying by rising water or settling mud. The remains may have settled in forests, swamps, or the sea floor. They may have been crushed under the weight of thousands of feet of rock or squeezed in the buckling layers of the Earth's crust. They may have rested under the ground 10 million years or longer. The history of a fossil fuel deposit determines the properties of the fuel and that in turn the way people use it.

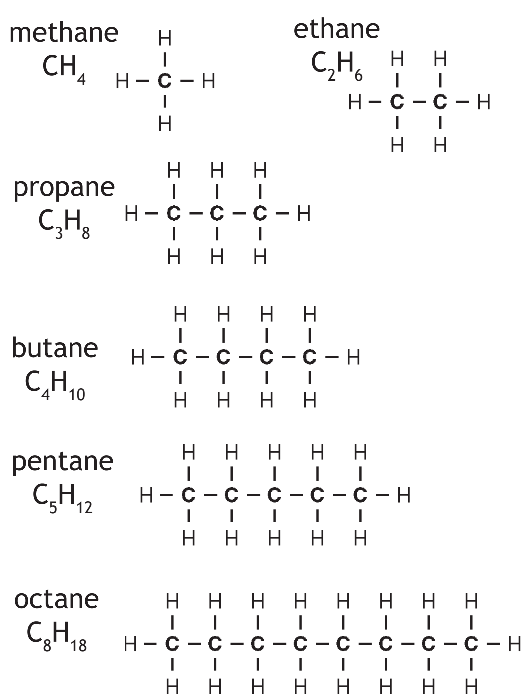
Question 3.1

Of the energy sources shown here, which are fossil fuels?



Hydrocarbons

Molecules composed of carbon and hydrogen atoms are called *hydrocarbons*. Oil and natural gas are mixtures of hydrocarbon chains of various lengths. In these molecules there are at least twice as many hydrogen atoms as carbon atoms. Each carbon atom can ***bond***, or stick to as many as four other atoms. Here are some simple hydrocarbon molecules with their chemical formulae.



A chemical formula shows the number of atoms of each type in a molecule. For example, CH_4 has one atom of carbon (C) and four atoms of hydrogen (H).

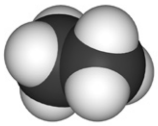
Petroleum and Oil

Most hydrocarbon molecules are liquids at room temperature. Liquid hydrocarbons are called *petroleum*. Some, such as octane, are used as vehicle fuels. Different length molecules produce different grades of fuel, such as gasoline, diesel, kerosene, and jet. Still longer petroleum molecules form thick liquids, called *oils*, that are particularly good for lubrication in vehicles and machinery. The longest molecules form heavy-duty, nearly solid, substances such as paraffin (wax) or asphalt (used in paving roads.)

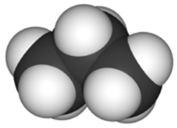
Hydrocarbon molecules are not flat and straight like chemical diagrams. Can you tell which atoms are carbon and which are hydrogen in the pictures below?

For the longer hydrocarbon chains the number of carbon atoms is used to name the molecule. For example, in Greek, okto= 8, pente=5, and deka=10. So, C_8H_{18} is called *octane*; while $C_{15}H_{32}$ is called *pentadecane*.

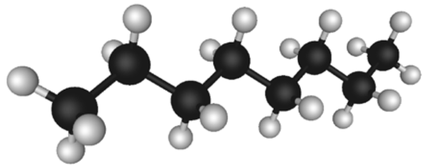
Question 3.2
What are the names of the molecules shown here?



A



B

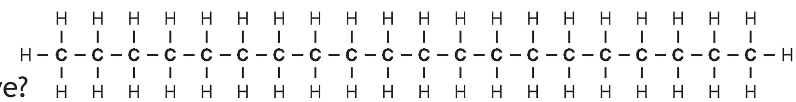


C

D

Nature does not neatly sort hydrocarbons for us. They are pumped from the ground in a mixture called *crude oil*. A *refinery* separates the crude oil into mixtures of hydrocarbons that are about the same length. In some cases long hydrocarbon chains are split into shorter ones. Most of the refined products are used for fuel. About half is gasoline. Other refinery products are lubricating oil, waxes, and raw materials for plastics and medicines.

Question 3.3
What would you call this molecule?
What properties would this substance have?



Natural Gas

The shortest hydrocarbon molecules (methane, ethane, propane, and butane) are gases—unless they are cooled or pressurized. They are the components of *natural gas*. Natural gas is often found in pockets above the deposits of crude oil. In early oil drilling, natural gas was not considered to be useful, so it was simply burned as waste. Eventually, people learned that natural gas is one of the cleanest-burning fuels, with very few air pollutants, making it desirable for heating and cooking. Now natural gas is captured and distributed through underground pipes in many regions of the country. The percentage of households using natural gas has increased dramatically over the past few decades, and natural gas has now replaced coal as the second most-used fuel in our society (after gasoline).

Refineries such as this one (Sun Marcus Hook refinery in New Jersey) produce a wide range of products, including gasoline, kerosene, oils, and asphalt. Refineries are usually located near ocean ports or pipelines where they can receive large quantities of crude petroleum, and send it off again after its refined, via ships called ***oil tankers.***

Coal

Living material always has molecules rich in carbon and hydrogen, but fossil fuels are not always hydrocarbons. In ancient swamps and flooded forests, plant material rested under water where there was little oxygen. Anaerobic bacteria, which did not need oxygen, fed off these dead plants, converting some of the plant material into swamp gas—mainly methane. The methane rising from the swamp carried away hydrogen, leaving behind mostly carbon, which eventually formed coal, a rock that burns.

Different classes of coal relate to age, hardness, and purity. Lignite *and* Subbituminous *coal are the youngest and least pure.* Bituminous *coal is the most plentiful, most widely used, and produces a lot of pollutants when burned.* Anthracite *is the hardest, purest, and least abundant type. It makes almost no smoke when it burns.*

Coal was a key fuel used during the industrial revolution, powering steam engines and metal smelting furnaces in industry as well as steam locomotives for railroads. One drawback of coal is the high level of impurities, which results in pollution when the coal is burned. The other is that, as a solid, coal cannot be transported easily or through pipelines. One possible solution to both of these problems is to refine the coal and turn it into a synthetic hydrocarbon gas fuel. This would add extra cost to the fuel and reduce its energy value, but the process of coal gasification is still being explored because of the possible environmental benefits.

Effects of Fossil Fuel Production

We all make mistakes. Some mistakes have more serious consequences than others.

The accidental grounding of the *Exxon Valdez* off the coast of Alaska in March 1989 spilled more than 10 million gallons of crude oil into the water and onto the beaches. The public was shocked. But what most people did not know is that oil spills are very common. More than 2,600 oil tankers sail the world's oceans. During the year that followed the accident in Alaska, accidental oil spills of more than 10 thousand gallons occurred more than twice a week!

The causes of oil spills are many. The *Exxon Valdez* ran aground by human error. Later that year an explosion set loose nearly 4,000,000 gallons of oil in the Gulf of Mexico. Lightning caused a spill of 3,000,000 gallons in Siberia. A collision between tankers dumped 3,000,000 gallons into the Mediterranean Sea. Bombing by guerrilla fighters dumped more than a million gallons of oil into Colombia's waterways. It was a typical year.

Pollution and oil spills are two hidden costs of our fossil-fuel-based system of energy production that are often ignored. If the health and environmental costs were included in our fuel prices, gasoline would cost much more.

Drilling and mining are messy operations that can pollute and scar the landscape. Strip mining involves removing the surface rock from many acres of land. This technique is a relatively safe and simple way to recover shallow coal deposits, and provides about half the coal for the United States. At present, as required by law, coal mining operators attempt to restore the landscape. The resulting land may be suitable for farming or development. Whether land reclamation can restore a wilderness area is still debated.

Question 3.4

What hidden costs of fuel need to be determined to compute the actual cost of a gallon of gasoline?

Oh Daddy, won't you take me back to Muhlenburgh county,
Down by the Green River where Paradise lay.
I'm sorry, my son, but you're too late in asking.
Mr --------'s coal train has hauled it away.

—from the song "Paradise" by John Prine

The story goes that Mr. -------- was angry when he heard this song. He did not think it was fair that the workers, managers, and owners of the coal company be held responsible for the impact of strip mining. His name is not printed here. The argument over what is fair is not settled.

What do you think?

Question 3.5

Who can fairly make the decisions about how coal is mined and where coal is mined?

Who should pay the cost of land reclamation?

Effects of Burning Fossil Fuels

When a fuel burns it combines with oxygen to produce heat. This explosive chemical reaction is called *combustion*. The chemical equation below reads, "Carbon reacting with oxygen produces carbon dioxide and heat."

$$C + O_2 \dashrightarrow CO_2 + heat$$

Carbon combined with hydrogen (hydrocarbons) contains more energy than plain carbon, the main ingredient in coal. Oil has more energy per unit volume than coal. Hydrocarbon combustion produces CO_2, water, and heat.

$$CH_4 + 2O_2 \dashrightarrow CO_2 + 2H_2O + heat$$

A *chemical equation* shows how atoms are rearranged during a chemical reaction. A number in front of a formula indicates the number of molecules. So **$2O_2$** means two molecules of oxygen, each of which has two oxygen atoms, for a total of four oxygen atoms. Do the number of atoms present before a reaction equal the number of atoms present after the reaction? Following is a list of symbols used in the equations:

C = carbon
O_2 = oxygen
CO_2 = carbon dioxide
CH_4 = methane
--> = produces

In a complete combustion, all carbon and hydrocarbon products are burned, producing just water and carbon dioxide, neither of which are toxic. However, levels of carbon dioxide in the atmosphere are rising because of the combustion of fossil fuels. Carbon dioxide is one of several gases in the atmosphere called *greenhouse gases*. These gases hold heat in the atmosphere. Increased levels of carbon dioxide from the burning of fossil fuels could increase the average global temperature in the coming decades, resulting in unpredictable climate changes.

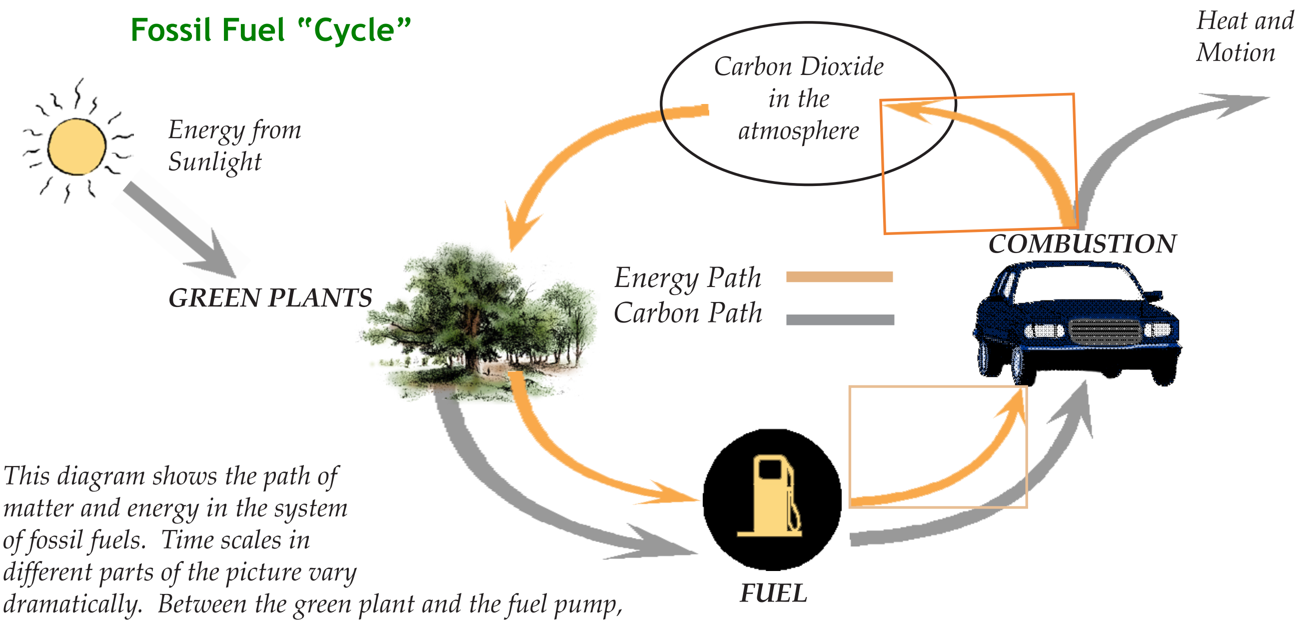
Unfortunately combustion is rarely perfect, and unburned hydrocarbons, soot, and carbon monoxide (CO) are produced. Nitrogen from the air enters the combustion reaction forming nitrous oxide (NO_2). Nitrous oxide and carbon monoxide are toxic gases, key ingredients of smog. Also, impurities in fuel result in other forms of air pollution, such as sulfur dioxide (SO_2). Sulfur dioxide and nitrous oxide combine with moisture in the air to cause acid rain.

Various technologies can reduce the amount of pollution. New cars have devices called *catalytic converters* to remove pollutants. Factories and power plants that burn coal can install a smokestack "scrubber," in which sulfur dioxide bonds to quicklime removing 50% to 90% of the sulphur dioxide before the waste gas is released into the air.

Question 3.6

Which one moves in a repeating cycle, matter or energy?

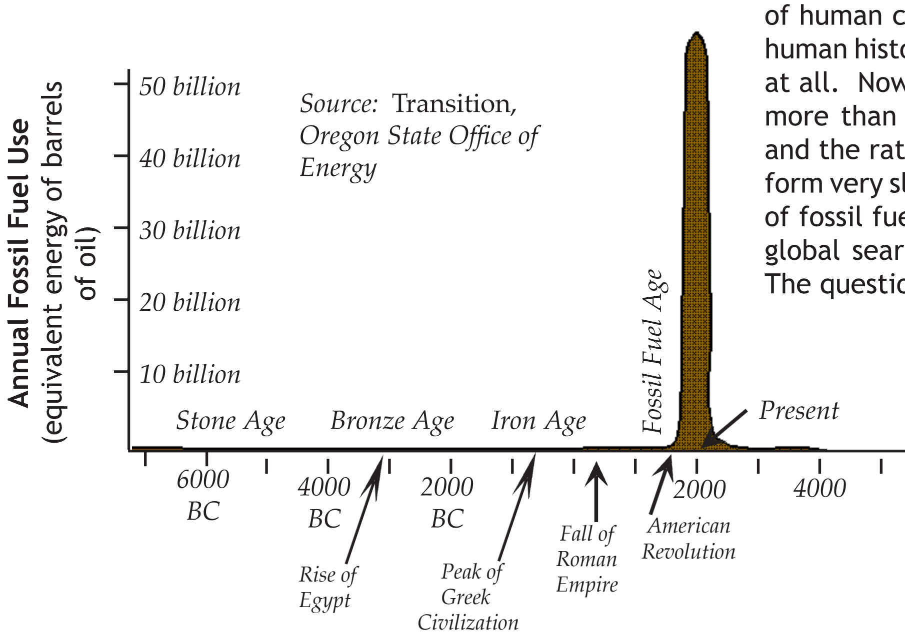
Fossil Fuel "Cycle"



*This diagram shows the path of matter and energy in the system of fossil fuels. Time scales in different parts of the picture vary dramatically. Between the green plant and the fuel pump, where energy-rich molecules are transformed to the fuels we use, part of the process happens naturally and part of it is done by the work of people. The natural part takes tens of millions of years to produce crude petroleum. Changing crude petroleum into fuel takes only hours in a refinery. The transformation of fuel into heat in a car takes **seconds!***

Fossil Fuel Use

Past—Present—Future?



A Limited Resource

The graph of **Fossil Fuel Use** shows the "Fossil Fuel Age" as just a blip in the course of human civilization. Throughout most of human history people did not use fossil fuels at all. Now humans burn the equivalent of more than 50 billion barrels of oil a year, and the rate is increasing. Since new fuels form very slowly, it is certain we will run out of fossil fuels if this continues, despite the global search for new fossil fuel deposits. The question is, "When?"

If we continue to burn fuels at a rate of about 300 quads a year, we will have fuel for at least 100 years. The table of **Estimated Fossil Fuel Reserves** shows the reserves for each fossil fuel. It assumes the rate of fuel consumption will not grow and no new reserves will be discovered.

Estimated Fossil Fuel Reserves (approximate quantities)			
Fossil Energy Source	Quantity of Reserves	Energy Content (quads)	Will last
COAL	1,000 billion tons	23,200	209 years*
OIL	1,000 billion barrels	5,300	45 years*
NATURAL GAS	3.7 trillion cubic feet	4,700	52 years*

** at the 1990 rate of consumption*

Source: World Resources Institute, World Resources, Oxford University Press,1994.

Question 3.8
In your opinion are these assumptions valid—the rate of fuel consumption will not grow and no new reserves will be discovered?

Question 3.9
What might happen in society when fossil fuel reserves run critically low?

Question 3.10
When and how should people plan for the transition from the Fossil Fuel Age to an age of other energy resources?

We usually think about the cost of fossil fuels in terms of how much it costs to buy a gallon of gasoline. But there are other costs as well. Mining, drilling, and transporting fossil fuels frequently disrupts habitats for plants and animals as well as for people. Wars have been fought over energy-rich territory, such as the oil fields that lie near the borders of Iraq and Kuwait, or Equador and Peru. Also, many people suffer from the effects of air pollution, and the long term use of fossil fuels is causing global warming.

Conclusion

We've found out what fossil fuels are, where they come from, how much fossil fuel is burned by people every year, and what effects that burning has on the environment. We've also looked into the future to see how long we have before we must find alternative sources of energy. Most of the energy we use in homes, schools, and offices is in the form of electricity. Think, for a moment, about the ways you use electricity.

You come home from school. Click, you flip on the light. You get a bottle of juice from the refrigerator. The refrigerator starts humming since the rush of warm room air triggers the cooling circuits. Beeps sound as you punch buttons on the microwave oven to pop popcorn. Click, you turn on the TV. If it's cold, the furnace comes on to warm the house. Electric appliances make a big difference in your life.

Image courtesy of pdphotos.org

Electricity typifies one of the main ideals of an energy-using society—convenience. We do not need to trouble ourselves with fuels or matches when the flip of a switch turns on our lights. Turn a knob and in minutes our food is hot. No collecting wood or shoveling coal for us!

When we hear the words "industrial society" we often think of factories and heavy machinery, not something clean and neat like the electricity we use in our homes every day. Yet electricity is a product of industry. The industry that generates and distributes electricity continues to grow.

Where does the electricity in your home come from? When you plug in a toaster, you know it's somehow connected to an electric meter at your home or apartment building, and then to electrical transmission lines outside. But where do the lines go? How is the electricity generated in the first place? In the next chapter, we will follow the lines all the way to the power plant and find out how electricity is generated to light and heat homes and businesses, and to run all the appliances we plug into our wall sockets. You may be surprised at the source of most of our electricity.

Investigation

How Much Energy?

The international standard unit of energy is the **joule**. Any amount of energy can be expressed in joules but sometimes it is helpful to use different units depending on the amount of energy, its origin, or its use.

Joule

The energy it takes to accelerate a one-kilogram mass at the rate of one meter per second over a distance of one meter.

Kilowatt-hour

Enough energy to keep a 100-watt light bulb going for 10 hours. An electric bill lists energy use in kilowatt-hours.

1 kWh = 3,600,000 joules

Calorie

The energy required to raise the temperature of one gram of water by one degree Fahrenheit. 1 cal = 4.2 joules. The energy content of food is measured in kilocalories (C) although they are usually called calories too.

1 food Calorie = 1000 cal.

Btu

British thermal unit. One Btu is the energy required to raise the temperature of one pound of water by one degree Fahrenheit.

1 kilowatt-hour = 3,411 Btu.

1 Btu = 1,055.4 joules.

Therm

100,000 Btu. One therm is the energy in 97 cubic feet of natural gas.

A household gas bill is often listed in therms.

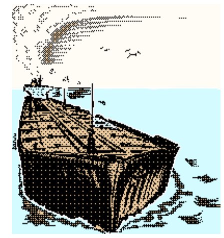
Barrel

Oil is measured by the barrel, which is 42 gallons. Burning this oil would release about six million Btu.

Oil Tanker

A typical oil tanker transports about three million barrels of oil. There are currently more than 2,600 tankers on the world's oceans and waterways.

Ton



Coal is measured by the ton, which is 2000 lb. The energy in one ton of coal is equivalent to about four barrels of oil.

Coal Train

An average coal train pulls about 100 cars, each of which contains about 100 tons of coal. A typical coal-fired electric power plant needs deliveries from about four coal trains every day.

Quad

One quadrillion (10^{15} or 1,000,000,000,000,000) Btu. You must burn 170 million barrels of oil or about 40 million tons of coal to get a quad. Energy use in the United States is 60 to 70 quads each year.

Question 3.7

How many joules in:

- one therm?
- one barrel of oil?
- one ton of coal
- train?
- tanker?
- one quad
- one coal
- a candy bar
- a typical oil

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4. Field Trip to a Power Plant

Follow the electricity back to its source . . .

Marty Hunt told us the power plant would be on the right, when we turn onto Tenth Street, and we couldn't miss it. There is no question we are headed in the right direction. Steel towers loom over the countryside holding up power lines that are spread out in all directions across pastures and green hills.

After getting our visitor's passes at the gate, we drive past acres of fuel oil storage tanks. At the power plant itself, seven smoke stacks, each well over 300 feet tall, rise from an immense box-shaped tangle of pipes, duct work, and cables. From one of the stacks a cloud of white smoke tumbles upward, a mixture of water vapor and carbon dioxide.

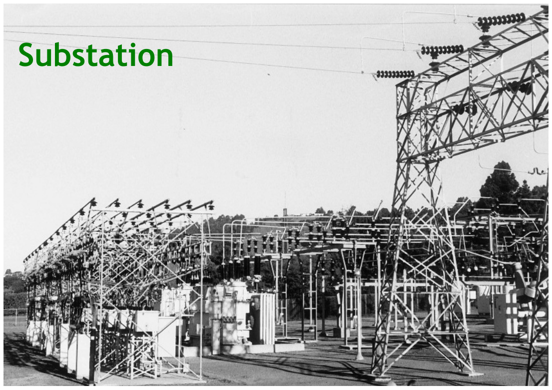
Mr. Hunt, a project manager at a power plant run by Pacific Gas and Electric in Pittsburg, California, meets us outside his office. "This plant, like many electric power plants, has more than one generating unit, each with separate boilers, steam turbines and electric generators," he tells us. "The Pittsburg Plant is like seven power plants in one. Each can burn either oil or natural gas, but natural gas is almost always used because it burns much more cleanly." Today only one unit is operating.

"It is a good day to look around. A major overhaul of two of the units is in progress. Some machinery is dismantled, giving a good opportunity for us to see the inner workings," he said. We put on hard-hats and begin the tour.

We thread our way up several flights of outdoor staircases to the platform where the generators are being rebuilt. The generator in a typical fossil fuel power plant is spun by a steam *turbine*.

Fossil fuel is burned to boil water in a *boiler*, creating steam at a high temperature and pressure. The steam from the boiler hits the fan-like blades of the turbine and causes it to turn. This is where the heat from the burning fuel that went into the boiler gets converted to spin the generator.

The turbine works best when the pressure of the steam going in is as great as possible and the pressure of the steam going out is as small as



Approaching the Pittsburg Power Plant.
Notice the numerous cooling towers on the far left and the large oil tank on the right.

possible, Mr. Hunt said. "In the newest and most efficient turbine at the Pittsburg Plant, the steam enters at a pressure of 3,500 psi [pounds per square inch] and at a temperature of 1,000 °F [more than 500 °C]."

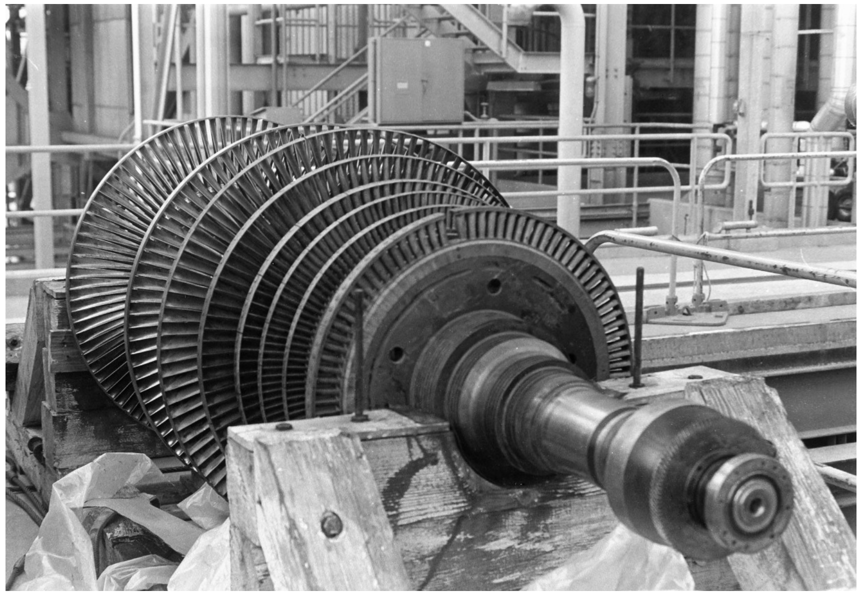
After the steam leaves the turbine it goes to the *condenser* to be cooled. As steam condenses to liquid water it contracts, reducing the pressure on the output side of the turbine to a small fraction of the pressure on the intake side.

Pressure

Psi stands for "pounds per square inch." Right now on every square inch of your body the atmosphere is pushing with a force of about 15 p.s.i.

Question 4.1
How many times greater is the steam pressure in the power plant?

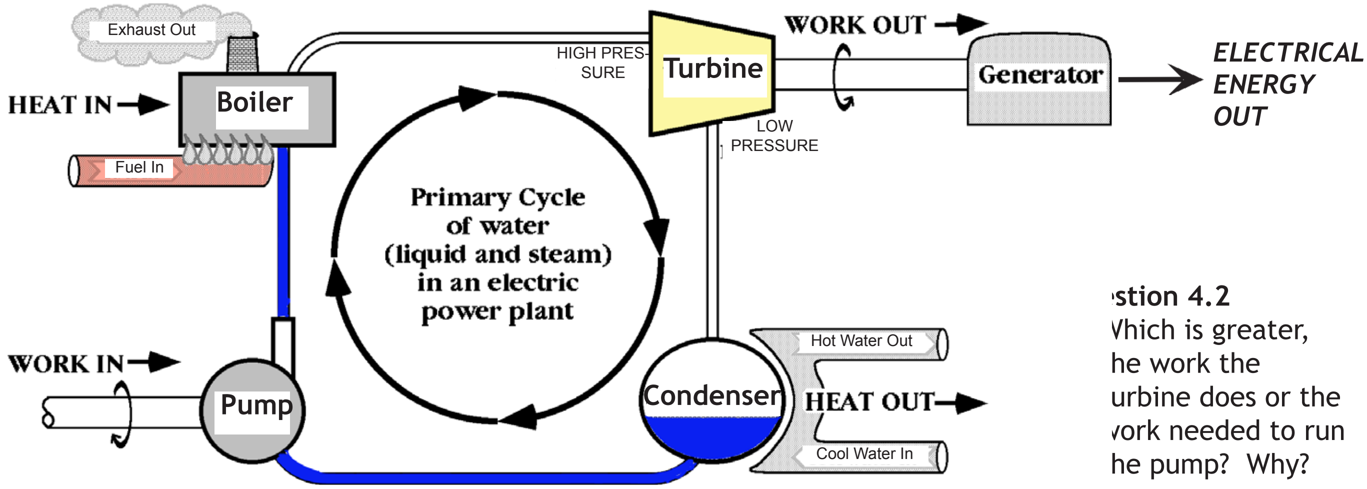
"Part of my job," said Mr. Hunt, "is overseeing the rebuilding of the condensing system. Cooling the steam for just one generating unit requires 2000 gallons of water every minute. Enormous pumps pull the water in from the freshwater bay next to the power plant. Elaborate moving screens filter out the larger bits of trash and natural debris. This water is then sent to the condenser to soak up the heat from the 'used' steam."



The inside of a steam turbine?
*This (above) looks like a steam turbine, but it actually is a **pump**. Think of a pump and a turbine as the reverse of each other. In a turbine, a fluid flows past the blades forcing them to turn. In a pump, spinning blades force the fluid to flow. The real **turbine** is encased in the housing shown in the photo below.*

If this heated water were returned directly to the bay, its temperature would disrupt the ecosystem. To avoid this *thermal pollution*, as it is called, the water goes through cooling towers which transfer heat to the air. Cooling towers are a prominent feature of many steam powered electrical generating plants. After passing through the cooling towers at the Pittsburg Plant, water goes through two miles of open channels before it reaches the bay. Even so, the water is warmer than the natural temperature of the bay. The warmth of the water, and the fact that the water contains the remains of small fish that have been sucked through the system, makes this part of the bay attractive to large fish. It is a favorite spot for fishermen.

Mr. Hunt leads us through the unit that is operating today. Down at the level of the boilers we feel the heat as we peek at the flames through tiny windows. The heat is well contained. The noise, mainly from fans, is loud. On the wall hangs a bin of ear plugs for workers who have to spend time here.



stion 4.2
Vhich is greater, he work the urbine does or the vork needed to run he pump? Why?

Water Circulates in a Closed Loop in a Steam Generating Plant

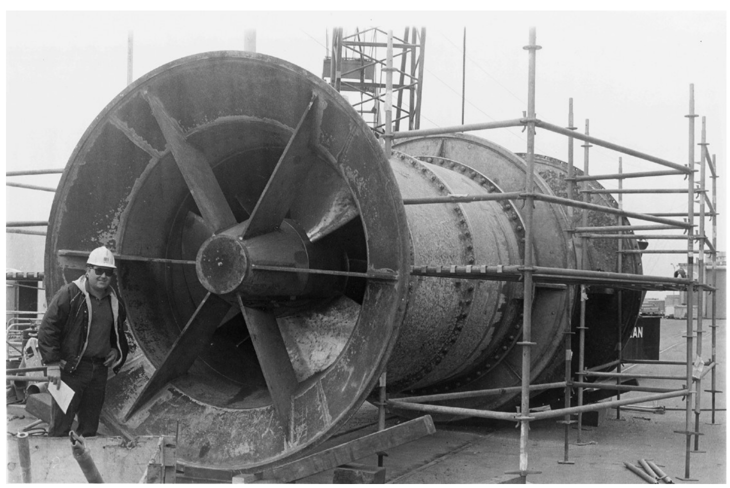
*In the **Boiler**, water is heated to produce high pressure steam.*

*In the **Condenser** the heat is removed to lower the pressure.*

*The work of the power plant is done in the **Turbine** by the steam that rushes from the high pressure boiler to low pressure condenser.*

*The **Pump** feeds the water back into the boiler to begin the cycle again.*

Up above, where the generator is running, there is not much to see. It is completely hidden in its housing, but you can feel the vibration of the rapidly spinning mechanism. The turbines, the generator, and a pump that pushes condensed water back to the boiler are aligned on a single shaft, which must turn at exactly 3600 rpm (revolutions per minute) to maintain the AC electricity frequency of 60 cycles/second. The electricity from the generators goes through high voltage transformers, in and out of acres of switching mechanisms, and then off across the countryside through power lines.



This pump pulls water out of the bay for condensing steam after it leaves the turbine. Marty Hunt stands next to it so we can see the size of the pump.

Some of the electricity that is produced is used right at the power plant. All the pumps, fans, generator exciter coils, and other miscellaneous electrical equipment needed to run each generating unit use several megawatts [a *megawatt* is a million watts]. "We are our own best customer," Mr. Hunt said.

We step into the control room. Three power plant operators are at their desks in front of panels full of switches and monitoring devices that stretch to the ceiling. Emergency warning lights are lit up on top of the control panels. Fortunately, these lights have no significance today because this control room is for one of the units that is shut down. Switches are tagged with labels declaring in bold print, "Man On Line," so that those systems are not be activated from the control room while a worker, man or woman, is working on it outside.

Ron Franklin at the Control Panel

When we ask what is involved in operating a power plant they joke, "You can see we do not need to dress up for the job. Not like in the nuclear plants where they all wear neck ties." Ron Franklin, a senior control operator who has been at the plant for 21 years, said, "In all seriousness, this job is a challenge. It takes a team to do it.

"Even though much of the process is automatic, and some of the work is routine, we are dealing with materials at extreme pressures and temperatures, and equipment moving at rapid speeds generating many megawatts of electric power. We are responsible for the safety of the equipment and the people who work on it twenty four hours a day.

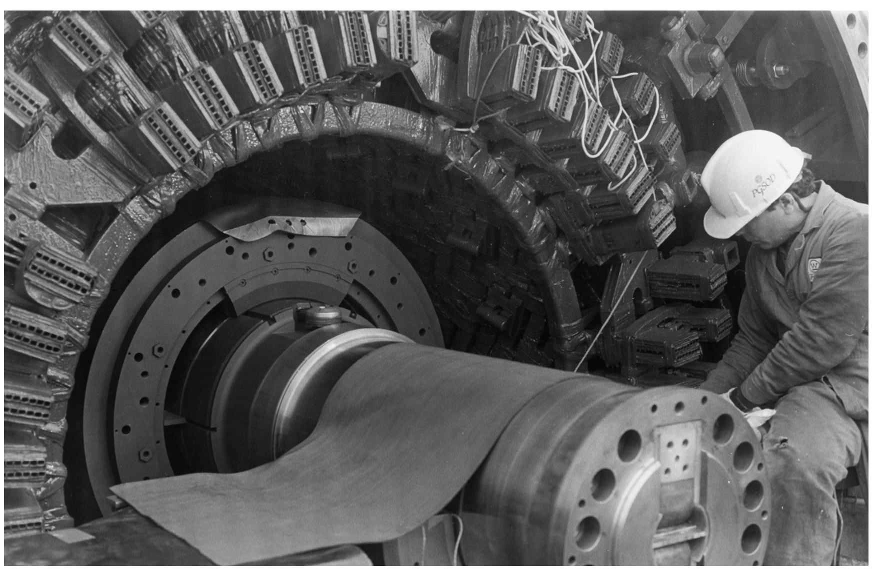
"When a steam pipe has a leak or a pump has stopped working the operators must keep the equipment from destroying itself and, if possible, keep the generator running at the same time.

"In addition to the control room for each generator there is a system control room for all the power plants in each region of the power grid. We get messages from the system control room in San Francisco about how the grid is operating and how much power is needed from our generator.

"I remember the time in 1989 when we lost contact with San Francisco. We didn't need any message to tell us that there was an earthquake. Besides the usual bumping and bouncing we had the added effect of shifting I-beams and swaying smoke stacks. There was no major damage at the plant, but power lines were down everywhere and electric current stopped flowing. When the current stopped flowing the load on the generator went down and the driving energy of the steam turbine made it spin faster. As the shaking settled after the quake the generator frequency rose up above the usual 60 cycles per second. Even though we were out of contact with the system operators in San Francisco, we figured out what was happening and decided what to do."

As we drive home, power lines stretch along the highway beside us. Perhaps they were the ones that carry electricity to the substation in our neighborhood. We left behind a system engineered to provide more than 2,000 megawatts of electricity. When it was built about 50 years ago it produced only a third as much. As people demanded more, additions and improvements were made. We expect additions to continue, especially outside the United States. Demand for power abroad is expected to grow 10 times faster than here. In China alone the use of electricity is expected to grow by 15,000 megawatts per year. That is like opening seven additional Pittsburg power plants every year.

The Pittsburg Plant, like many others, is a fossil fuel burning plant. We wonder how many future power plants the Earth can provide fuel to run? We stop for gas—our tank is low.



A worker at the armature of a multi-megawatt generator

A Survey Of Power Plants

Electric power flows into the grid from a variety of different kinds of power plants. Each kind has its advantages and disadvantages. As you learn about each kind consider the following questions.

- ***What is the source of the energy that feeds the power plant?***
- ***What energy transformations occur between the power source and the output of electrical energy?***
- ***Is the energy source renewable?*** (An energy source is said to be *renewable* if it can be replenished at least as fast as it is used.)

Question 4.3
What is the ultimate source of the energy that feeds a fossil fuel power plant?
[Hint: It's not the fossil fuel!]

Question 4.4
What energy transformations occur between that ultimate power source and the output of electrical energy?

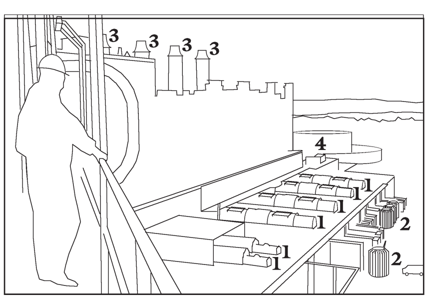
Fossil Fuel Power Plants

In the United States, 2,110 power plants burn fossil fuels (coal, oil, and natural gas) generating about 73% of the nation's electrical energy. Most of the plants use steam to drive the turbines, like the one in Pittsburg, California. Some of the plants use the hot gases from combustion of fuel to turn the turbine directly, and a smaller number use large internal combustion engines, like those that run cars and trucks, to turn the generators.

The main advantage of fossil fuel power plants is that daily operating costs are relatively low. So many have been built that engineers have learned to construct them so they are very efficient. Some of the disadvantages are:

- They emit pollutants such as nitrous oxide and sulfur dioxide.
- Mining coal and drilling for oil and gas are expensive, dangerous, and often injurious to the environment.
- Transportation of oil has resulted in hundreds of accidental oil spills.
- Fossil-fuel power plants are the main source of acid rain.
- Fossil fuels are a nonrenewable energy source. Current reserves will be gone long before new ones are formed .
- Fossil fuel power plants are major contributors of "greenhouse gases" to our atmosphere—40% of the carbon dioxide added to the atmosphere comes from fossil fuel power plants.

All these disadvantages are "hidden costs" that make it difficult to assess the real costs of electricity.



Find These Items in the Photograph:

1. **Generating Units** *(which include the turbine, generator, and the boiler feed pump)*
2. **Transformers**
3. **Smoke Stacks**
4. **Oil Storage Tank**

Nuclear Power Plants

In December 1993, the total number of nuclear power plants in the United States was 109, collectively producing 610 billion kW-hrs of electricity. As of 2004, nuclear power plants were producing about 20% of electric power in the United States. They are fueled by enriched uranium. In nuclear fission, the nucleus of a uranium atom becomes unstable and splits into two smaller nuclei. That splitting produces heat. The heat boils water to drive steam turbines.

Question 4.5
What is the ultimate source of the energy in nuclear power plants?

Question 4.6
What energy transformations occur in nuclear power plant?

In normal operation, nuclear power plants do not emit air pollutants or greenhouse gases. Very small quantities of fuel can produce large amounts of energy. Energy analysts weigh these advantages against the following disadvantages.

- Uranium is a nonrenewable fuel.
- Thousands of tons of highly radioactive waste is left over and stored in containers. The radioactive waste will remain dangerously radioactive for many thousands of years and must be stored in safe waste storage facilities for those long time periods. However, no "permanent storage solution" has been accepted.
- Accidents can have widespread repercussions. In the former Soviet Union, the Chernobyl nuclear power plant exploded, spreading radioactive material into the air eventually killing and injuring many people. In the United States, a serious accident was narrowly averted at the Three Mile Island nuclear plant in Pennsylvania.
- Waste ores from uranium mines present a health hazard.
- Nuclear power plants are costly, and insurance companies will not insure them because the consequences of accidents are so severe.
- A nuclear plant operates for 30 to 50 years, and then it must be shut down (decommissioned). Decommissioning a nuclear power plant is very costly, since many components are highly radioactive.

Nuclear Power Plant at Diablo Canyon, California
Energy comes from a fission reaction that breaks the bonds holding the nucleus of atoms together. That nuclear reaction releases a tremendous amount of heat, which heats water in the dome-shaped containment buildings.

No new nuclear power plants are planned for the United States, however Japan and some countries in Western Europe depend heavily on nuclear power.

Geothermal Power Plants

Anyone who has seen pictures of lava flowing out of volcanoes is aware that the interior of our planet is hot enough to melt rocks. This heat comes from naturally occurring minerals, such as uranium, which consist of atoms that break down, or *decay*. When these atoms decay they are changed into lighter elements and they release heat. In some places the molten rock comes fairly close to the surface, but not so close that it erupts as a volcano. However, it may heat groundwater creating hot fountains of water called *geysers*. These are good sites for geothermal power plants.

Power plants that use the naturally occurring heat within the Earth to drive steam turbines are called ***geothermal*** power plants. Geothermal energy is a very clean energy source when compared with either fossil fuel or nuclear power. There are a number of sites especially suitable for this, including areas of Northern California, Wyoming, Hawaii, New Zealand, Japan, and Iceland.

Question 4.7
What is the ultimate source of the energy in geothermal power plants?

Hawaii is an excellent candidate for geothermal power production. On the Big Island, where there are active volcanoes, a geothermal project is underway. However, local opposition to this project believes the geothermal plant is an unacceptable intrusion into the local ecology as well as an insult to Pele, the goddess of volcanoes. Nearby inhabitants say toxic fumes are vented and make them sick.

Question 4.8
What energy transformations occur in geothermal plants?

A major advantage of geothermal energy is the magnitude of the energy source. The Earth has a tremendous amount of heat in it and our use of that energy is limited only by the technology we can devise to tap it.

Though the source is large, it is also unreliable. As steam is drawn from the ground, and as the surface of the Earth goes through natural changes, the energy available at a particular geothermal site can drop. The largest geothermal plant in the world is at Geysers in Northern California. It originally had a generating capacity of 500 megawatts, but currently operates at only 60% of that level.

The Geysers Geothermal Plant in California. *There are no smokestacks at this plant. Notice the mist rising from the cooling towers. Photo courtesy PG&E.*

Solar-Thermal Electric Power Plants

In a solar-thermal power plant, sunlight is reflected by a field of many large mirrors, and concentrated onto a tank of molten salt. The heat of the molten salt is used to boil water and produce steam, which turns a turbine for production of electricity. The mirrors are controlled by computers so they track the Sun along its path across the sky. Solar-thermal power plants have the advantage of being clean energy sources with no fuel costs. The source is considered renewable because sunshine is not depleted.

The main disadvantage of solar-thermal electric power is that the energy must be stored or backup systems employed for times when the sun is not shining—at night and on cloudy days. Possible storage systems include storage batteries, pumping water from a low reservoir to a high reservoir for later use with a hydroelectric generator, and production of hydrogen for later use in a fuel burning power plant.

Question 4.9
What is the ultimate source of the energy for solar-thermal electric power plants?

Question 4.10
What energy transformations occur in solar-thermal electric power plants?

Solar One Electric Power Plant near Barstow, California.

Thermoelectric Plants

All the power plants described so far depend on the direct use of heat. In each of the power plants we've seen, heat, converted to work in a turbine, drives the generator. Such power plants are called *thermoelectric* power plants. Fully understanding these power plants requires some knowledge of *thermodynamics*—the study of heat and work.

You will find out more about thermodynamics in chapter 8. For now, there are just two things you need to know.

1. Converting heat to work in most thermoelectric power plants is only about 30% efficient. That means that 70% of the heat is not converted to electricity. The wasted heat is carried away by hot water from the condenser.
2. The inefficiency of a thermoelectric power plant is *not* because of poor design. According to the laws of thermodynamics, the process of doing work with heat *must* be inefficient. It takes a *good* design to reach the 30% range.

***Efficiency* is a measure of what you get out for what you put in.**

$$\text{Efficiency} = 100\% \times \frac{\text{useful work}}{\text{energy used}}$$

Not every power plant is limited to 30% efficiency by the laws of thermodynamics. On the following pages are descriptions of some power plants that are *not* thermoelectric.

Hydroelectric Power Plants

A hydroelectric plant uses the force of gravity acting on water to drive its generators.

There are currently 1,253 hydroelectric power plants in this country, located along major rivers. Together, they produce about 12% of our nation's electrical energy. The most efficient systems are large dams that create deep reservoirs of water. High water pressure is ideal for driving water turbines. Hydroelectricity is a clean energy source in terms of pollution. It is relatively inexpensive, and requires no fuel because its ultimate source is the Sun, which drives the water cycle that fills reservoirs. Disadvantages include:

- Large tracts of land must be submerged under reservoirs, destroying sections of land ecosystems, disrupting the life cycle of fish and aquatic ecosystems.
- Reservoirs fill up with silt carried by river currents. The lifetime of a typical hydroelectric plant is 50 years until the reservoir is too full of silt to be useful.

Hydroelectric power plants have already been built at nearly all of the suitable sites. The few potential sites that remain are controversial because they involve the flooding of wilderness areas. Consequently, it is not likely that any new hydroelectric power planets will be built in the United States.

Question 4.11
What is the ultimate source of the energy in hydroelectric power plants?

Question 4.12
What energy transformations occur in a hydroelectric power plant?

Hydroelectric Power Plant
The building houses the water turbines and generators. Water comes through the pipes from a reservoir high up the mountain side. It is the difference in altitude between the reservoir and the turbines that give the water its potential energy. Photo courtesy of PG&E.

Wind Generators

Hundreds of years ago, wind power was used to turn grain grinding mills. When you drive by old farms and ranches, you often see old-style windmills that were used to pump precious water for irrigation. Most modern windmills are being used to generate electricity. For wind machines to generate significant amounts of electricity, the wind must be at least 20 miles per hour. It is wise to conduct detailed wind surveys of a site to determine annual wind variations, before deciding to install wind electric generators.

Disadvantages of wind power include:

- Birds can be killed by spinning wind turbines.
- People living nearby may object to the noise and appearance of wind turbines.
- Even at windy sites, wind is an intermittent event, so wind electric generators alone cannot provide all our electrical needs. Either the generators must be linked into a public utility to supplement other electric power sources, or the wind generators must have their own system of storing electricity for use when there is no wind. Storage systems such as those used with solar-thermal electric power can be used to store electricity from wind generators.

The main advantages to wind electric power generation are that it does not pollute the air or water, and has no fuel costs.

Question 4.13
What is the ultimate source of the energy in wind generator systems?

Question 4.14
What energy transformations occur in wind generator systems?

Wind Turbines. *One of three huge "wind farms" located in gaps in California's mountain ranges along Interstate 10 near Whitewater, California.*

Investigation

Home Heating Dilemma

"Mom, Dad, the newspaper has this great article about natural gas. It's clean and it's cheap, and it might be getting cheaper. I think we should get rid of our electric heating system and switch to natural gas."

"Hold on!" said Mom. "Didn't you know that the electric power in this area comes almost entirely from natural gas? There is no need to switch."

"That's right," added Dad. "What's the difference whether the gas is burned in our furnace or in some electric power plant?"

1. Burn it in a furnace in your house. You will either have it delivered through a pipeline or have containers delivered as needed to your home.
2. Have the utility company burn the gas and convert about 30% of the energy to electricity that will come to your home conveniently through the electric power lines to an electric heater.
3. Move into a neighborhood where a gas-burning power plant is to be built, and where there is a plan to pipe hot water from the condenser into nearby homes where it can be used for home heating.

Question 4.15

What is the difference if gas is burned in your furnace or in some electric power plant?"

What are the pros and cons of each of the three ways to heat a home with natural gas?

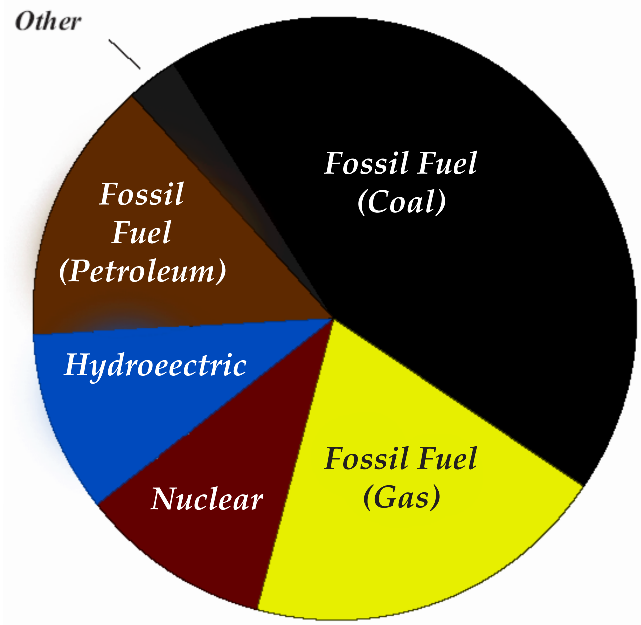
Investigation

The Future of Electric Power Production

Question 4.14
What percent of electrical power in this country is from burning fossil fuels?
How do you think the percentages of different plants will change in 50 or 100 years?
Why?

Question 4.15
Imagine a developing nation, such as China, hired you to advise them on what types of power plants they should build to provide their citizens with lights, TVs, and other modern conveniences. What kind(s) of power plants would you recommend?
Why?

Source: Energy Information Administration of U.S. Dept. of Energy, 1998 data.	**Number of Power Plants**	**Megawatts of Power**	**Percentage of Power**
Fossil Fuel (Coal)	1,198	325,001	43.3%
Fossil Fuel (Gas)	2,148	147,260	19.6%
Fossil Fuel (Petroleum)	3,321	76,511	10%
Hydroelectric	3,352	73,202	9.7%
Hydro Pumped Storage	141	18,669	2.4%
Nuclear	107	107,632	14.3%
Geothermal	27	1,746	0.2%
Solar	11	5	less than 1%
Wind	19	14	less than 1%
Wood	8	261	less than 1%
Total	10,332	750,301	100%



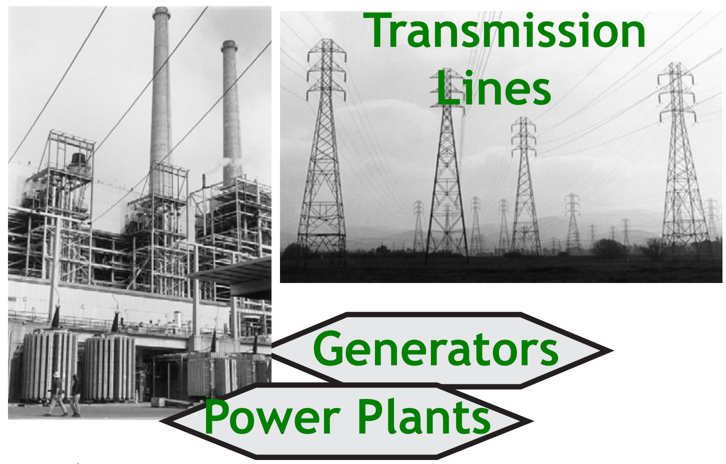
Conclusion

The size of the U.S. electrical power industry is vast: 6,667 operating fossil-fuel plants; 3,352 hydroelectric plants; 107 nuclear power plants—plus all the substations and connecting power lines. The costs for running and maintaining this industry is about $200 billion per year. The impact of this industry on the environment is immense. But power plants are only part of the picture. How we get the electrical energy from the power plant to your home is the subject of the next chapter.

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/9eu.html. We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

5. America Plugged In

Returning to the chain of technologies that brings electricity from a power plant all the way to your home, we now move to the next part in the chain where electricity is carried from the power plant through high voltage transmission lines, power substations, lower voltage transmission lines, home meters, and finally to home appliances. This chapter is about the network of cables that brings us electric energy and how it grew.



No Free Lunch—No Free Energy

An Energy User's Fantasy
As long as the power plant generator is spinning
I can get as much electric energy as I want from it.
It takes hardly any work to make the generator spin.

It does not work that way in real life. In real life, if you push on something it always pushes back on you, even if it is just an electron. The more current that flows from a generator, the more force it takes to make the generator turn.

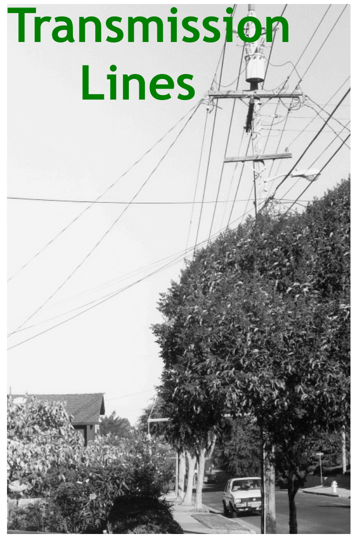
The more work the generator does for you, the more work you have to do to run the generator.

This should not surprise anyone who knows the law of conservation of energy *(energy is never created or destroyed)*. A generator cannot make energy. It transforms energy from one kind to another.

Wiring Up the Country

In the mid 1800s, electric wires were strung around the country, not for carrying electric power, but for sending information by telegraph. Telegraph equipment required low power, which was provided by batteries.

With the invention of the arc lamp the demand for electric power grew. In an arc lamp, the electricity jumps through the air across a gap between two carbon conductors, generating enough heat to vaporize the carbon and make it glow white hot. Arc lamps produced a very bright light—too bright to be used in the home. They also produced an acrid smell and soot. Their use was at first confined to mines, factories, street lights, and theaters.



> In Thomas Edison's view, persistence was a key to success: "Genius is 1% inspiration and 99% perspiration."
>
> In his endeavor to build a better storage battery, he made 8,000 attempts. "Well, at least we know 8,000 things that don't work," he is reported to have said.

Many inventors struggled to develop a more convenient electric light made from a glass bulb with a wire inside that would glow brightly when electricity ran through it. Today we call it an *incandescent light bulb*. The person who won the race to develop and patent the first practical incandescent light bulb was Thomas Alva Edison. The challenge was to find a material that would make a suitable glowing wire, called a *filament*, without burning up. Such a light would be useful in homes, resulting in many customers for the electric companies.

To help him solve the problem, Edison founded a large research institution in Menlo Park, New Jersey, eventually employing more than 100 people. Platinum was promising, but too expensive. After hundreds of trials, Edison settled on carbonized bamboo fibers as the best material for a filament to create the first marketable light bulb. To keep it from burning up, he pumped the air out of the bulb. Within a few months, he set up a demonstration of the new lighting system at Menlo Park. The demonstration so encouraged investors that he soon had enough money to light up the buildings on an entire block of New York City.

Edison was not just an inventor. He was a shrewd businessman. His purpose was not just to sell light bulbs, but to sell electric energy. His very successful company, Edison Electric, was later purchased by industrial financier J. P. Morgan, and merged with other companies to form today's huge General Electric Company.

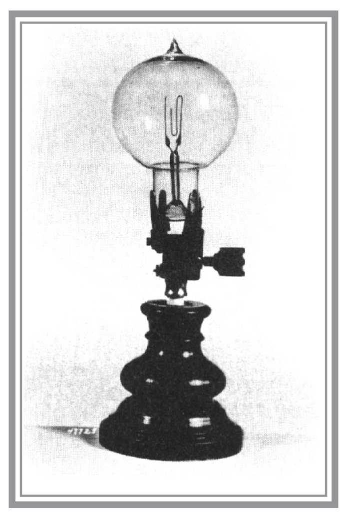
Louis Howard Latimer (1848-1928)

Early incandescent light bulbs were difficult to make and prone to failure. Making a carbonized filament meant shaping plant fibers and heating them to high temperatures without cracking them or burning them up. The challenge of building a better light bulb sparked a flurry of creative activity by the most inventive minds. One of these geniuses was Lewis Howard Latimer who developed his natural ability as an artist into skills as a draftsman, inventor, engineer, and legal consultant.

At age 10 Latimer was working for his father, an escaped slave, hanging wallpaper. His interest in reading and writing led him to become an office assistant for a law firm. After serving in the navy in the Civil War, he worked at the offices of patent attorneys, taught himself drafting, and patented a variety of his own mechanical inventions.

The United States Electric Lighting Company hired Latimer and he invented a new process for making carbon filaments for incandescent lamps. By stamping the filaments from sheets of pressed fibers and sandwiching them between boards that would expand with heat precisely the same amount as the filaments themselves, Latimer was able to mass produce a reliable light bulb. He invented fixtures and switches for the light bulbs and helped install lighting systems and light bulb factories in the United States, Canada, and England.

Latimer later joined Edison-General Electric, and although he continued to distinguish himself as an engineer, he became increasingly involved with patent law. General Electric and Westinghouse, usually rivals, both employed Latimer's talent regarding legal issues in the electrical industry.



Latimer Lamp with a Latimer socket and switch

To find out more about Louis Howard Latimer, search the Internet, or see the Global Systems Science website, http://lhs.berkeley.edu/gss/ for relevant links. Follow the path to GSS update links to Energy Use, Chapter 5.

The AC—DC War

The cylinder at the top of the power poles are "step down" transformers that bring the neighborhood power line voltage (720 volt) down to household voltage (120 or 240 volts).
Image courtesy of wikipedia.org

The course of electrical development in America was changed by the ideas of a Serbian electrical engineer named Nikola Tesla. He arrived at Edison's door in 1884 as an immigrant fresh off the boat from Europe with only four cents to his name and a reputation as an innovative engineer and problem solver. Edison hired Tesla. When the equipment broke down Tesla could fix it. In fact, he not only fixed it but he redesigned it and improved it. But what Tesla really wanted to do was scrap it, because it all ran on DC (direct current).

Tesla believed that AC power (alternating current) should replace DC. AC generators were more efficient and reliable. Edison's light bulbs ran on either AC or DC, so that was not a problem. Electric motors that were used for running all sorts of machinery, from fabric looms to drills and lathes, all ran on DC. But Tesla invented several efficient and reliable motors that ran on AC.

The most important advantage of AC was in long distance transmission lines. Transmission lines lose electrical power because of resistance. ***Resistance*** is the tendency of a wire to heat up when electricity flows through it. The longer the wire and the higher the electric current, the greater the resistance and the greater the loss of electricity.

The solution to the problem was to lower the electric current. ***Current*** is a measure of the number of electrons flowing through a wire. ***Voltage*** is a measure of the force on the electrons, pushing them through the wire. By reducing the number of electrons that flow (current), while increasing the force on each one (voltage), it is possible to deliver the same amount of electric power, but without heating the wire as much.

A device to transform the voltage and current, while keeping the power the same, is called a ***transformer***. At the power plant, transformers convert the voltage to at least 230,000 volts. Some operate at 765,000 volts. At ***substations***, transformers lower the voltage to 720 volts—too high for use in homes, but high enough to travel several miles efficiently. Smaller transformers at the top of utility poles step down the voltage to 120 volts or 240 volts for use in homes.

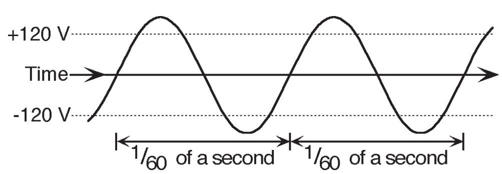
Transformers *operate* only with AC. Tesla realized, as electric power spread, Edison's DC system would become impractical. Still, Edison was stubborn. His DC systems were built and running, and customers were already paying. Edison saw no need to transport electrical energy over long distances, so for him DC was adequate.

Edison and Tesla disagreed on more than AC and DC. Tesla disliked Edison's method of problem solving by persistent trial and error. He believed that theory and calculation were the road to enlightenment. Edison, in turn, thought Tesla's theories looked fine on paper but were not practical. They also disagreed on how much Tesla should be paid.

Tesla resigned from Edison's company. Within a year his ideas came to the attention of George Westinghouse, whose invention of the air brake and other railroad technology had made his company one of the industrial giants. He decided to enter the electric power industry using Tesla's AC generating and distribution system. Here was a real competitor to Edison-General Electric. The battle between AC and DC began in earnest.

Having no scientific justification for promoting DC over AC, Edison and his electric company played on the public's fears. They put on demonstrations of the dangers of Westinghouse's system by publicly electrocuting pets and farm animals with AC. (They could have done it just as well with DC.) They even made sure that the state of New York bought Westinghouse's products for its first electric chair. People might hesitate, they supposed, to light their homes with the technology of execution.

In 1893, the Columbian Exhibition in Chicago was lit by Westinghouse using Tesla's generators and the nation saw the safety and reliability of the AC system. The preeminence of AC was firmly established when Westinghouse won the right to harness one of the great symbols of natural power in North America—Niagara Falls.

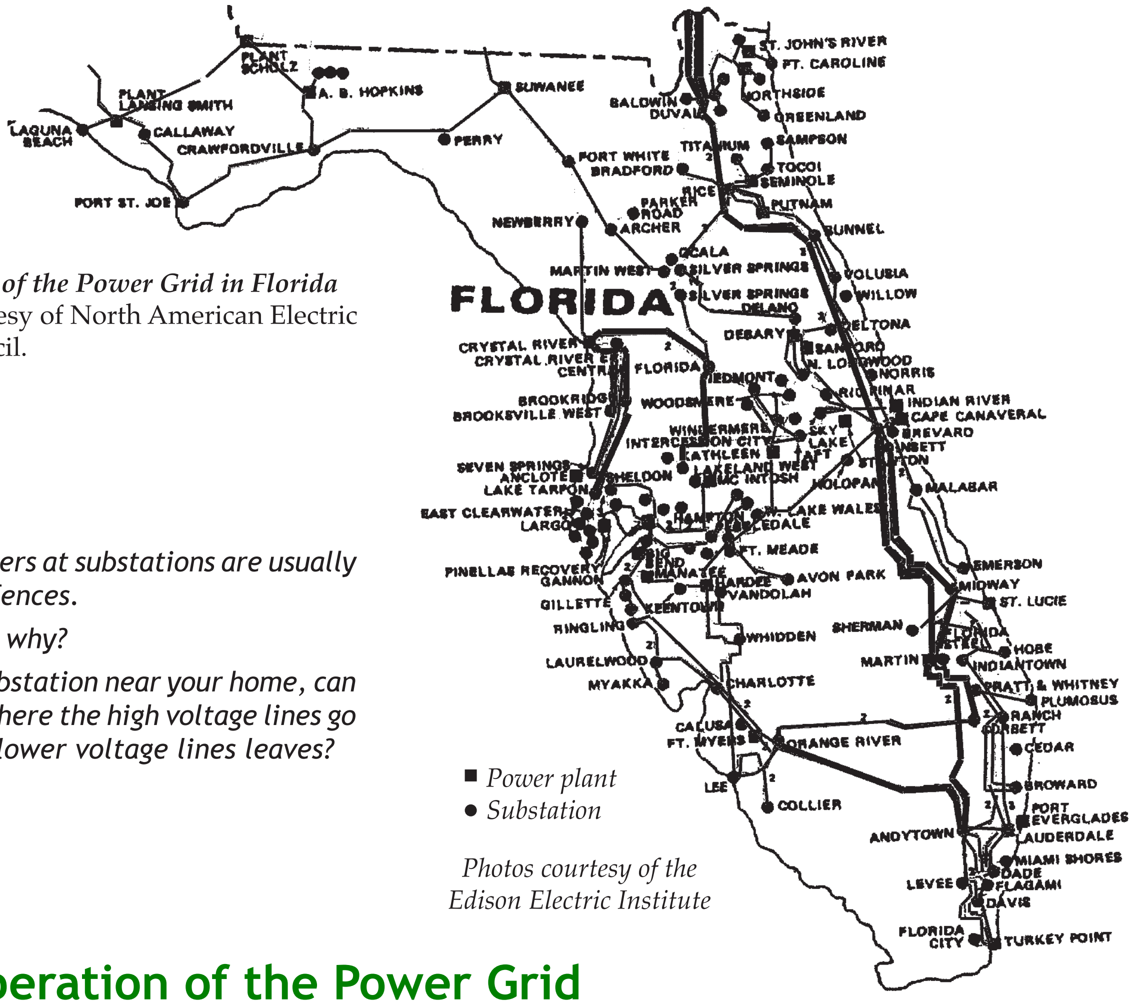


The Rise and Fall of AC Voltage
The voltage of standard outlets is 120V.
In reality the voltage fluctuates in a regular pattern sixty times every second. The power of this AC voltage is equivalent to the power supplied by 120V DC.

The Power Grid

As electric companies grew, power plants were linked together in networks which covered different regions of the country. Different networks provided different frequencies of alternating current, ranging from 25 to 60 cycles per second. Continued growth and development required a standard for the country. The Federal Energy Regulatory Commission (FERC) and state utility commissions were organized to coordinate the growth of huge power networks, containing hundreds of power plants, called the *electric power grid*. The power grid links users and producers of electrical power in the United States and parts of Canada.

In order for different generators to feed power into the grid, they must be working at the same speed to produce the same frequency of AC. Sixty cycles per second is the standard for the power grid in the United States. Each generator must be pushing the current forward at the same time, and each must reverse the current at the same time. If one generator is shut down for a while, it must be brought up to speed before it is connected to the others so that all the generators operate synchronously with each other. Each generator operates in lock-step with every other generator; and all of these power plants are connected to street lights, factories, homes, and businesses.



Sectional Map of the Power Grid in Florida
Diagram courtesy of North American Electric Reliance Council.

Photos courtesy of the Edison Electric Institute

Question 5.1

The transformers at substations are usually behind large fences.

Can you guess why?

If there is a substation near your home, can you identify where the high voltage lines go in and where lower voltage lines leaves?

Daily Operation of the Power Grid

Imagine millions of people returning home at the end of a hot work day in summer, turning on lights and air conditioners. As the load on the power grid increases, more energy is required to turn the generators. At first they slow down. Voltage goes down. AC frequency goes down.

This would be an emergency if it were allowed to continue. Electrical usage requires about 120V at almost exactly 60 cycles per second. Before the frequency drops even to 59 cycles per second the change is detected in the *system control room*, which monitors the operation of the power grid for a power company's service area. Idle power plants are brought back on line. The power generated matches the load and the frequency goes back to 60 cycles per second.

In the early evening, people switch off lights and appliances as everyone goes to bed. As the load goes down, generators are disconnected from the grid. This cycle happens every day.

What Next for the Power Grid?

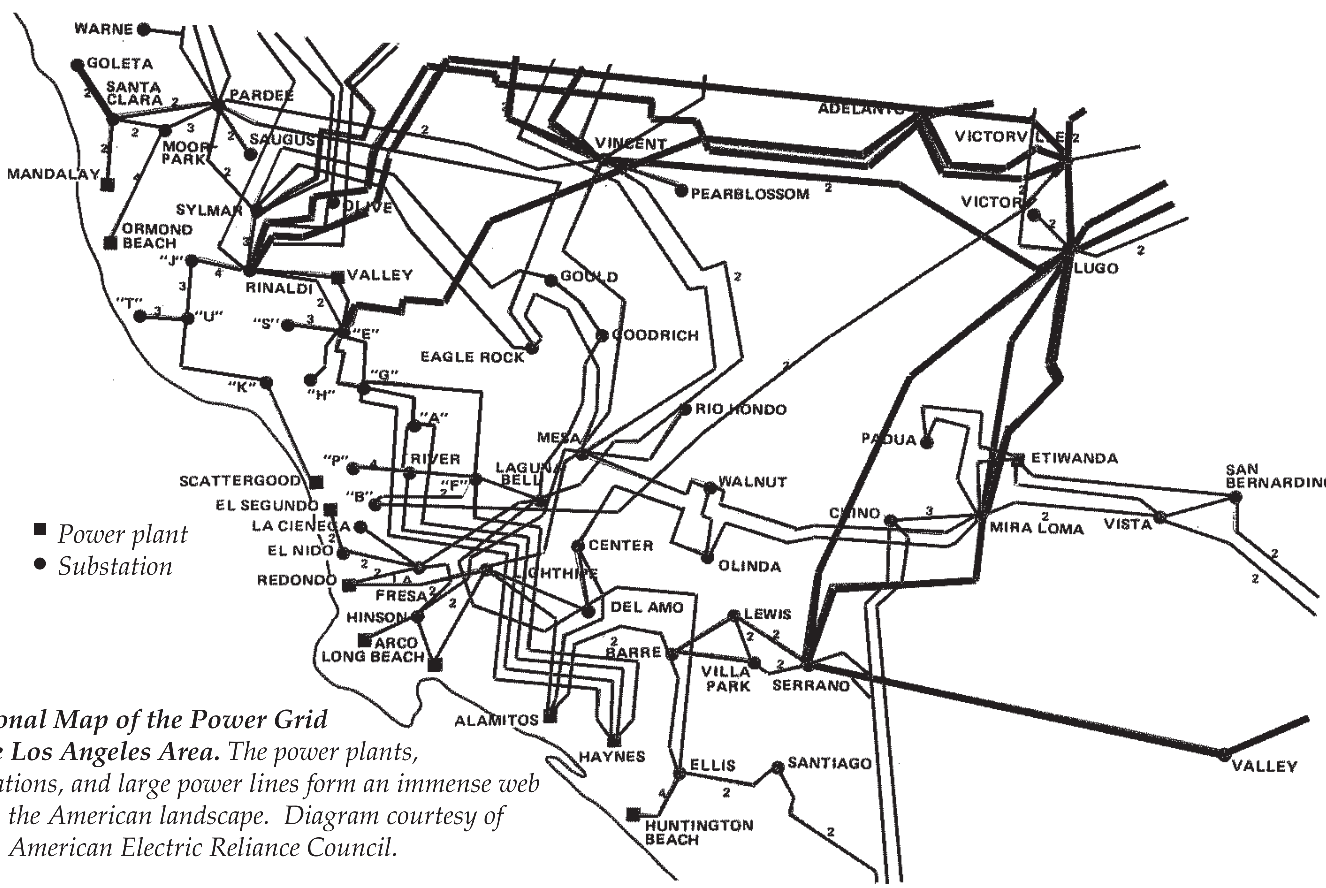
The current state of the telephone system gives us some glimpses into the future of electric power in the United States. Until the 1980s, telephone customers had no choice about which telephone company provided their long distance service. Now there are several companies you can choose from when you make a long distance call. To stay in business, each phone company must give callers a reason to use their phone service rather than another company. Competition among the companies is supposed to keep the level of service high and the costs low.

The future of the electric power system may be similar to the present state of the telephone system. Electric companies have not had to advertise to get customers to buy their power. Until now, electricity consumers have had no choice. The local electric company owns all the power in the wires that come to the customers, and the local electric company collects income. That is changing in many parts of the United States. Electric power distributors will have to give customers a choice of generating companies, and generating companies will have to compete for business.

Recognizing that their role is to provide service to their customers, rather than just electricity, many utility companies are actively encouraging conservation of energy, giving rebates for customers who insulate their homes or buy energy-efficient refrigerators. Whether utilities will continue to encourage energy conservation when they start to compete in the marketplace remains to be seen.

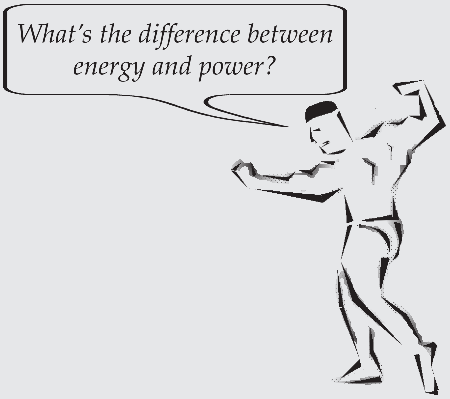
Conclusion

A fundamental property of matter—electric charge—has enabled our society to distribute energy through cables to our homes and businesses. To the customer, it has the appearance of being very clean, and it is certainly one of the most convenient forms of energy. We know, however, the energy that comes out of the electric power grid must first be fed into the grid from power plants, which burn fossil fuels. We can affect our impact on our environment, not only in our choices of energy sources, but in the way we use energy—in its *end uses*. Most of the remainder of this book concerns the end uses of energy.



Sectional Map of the Power Grid in the Los Angeles Area. *The power plants, substations, and large power lines form an immense web across the American landscape. Diagram courtesy of North American Electric Reliance Council.*

Energy and Power



You are browsing in a store to buy a light bulb to replace a burnt-out bulb. Will a 60-watt bulb be bright enough? Were you satisfied with its brightness? How about a 75-watt bulb? Why not a 100-watt bulb? What is a *watt* anyway? *Watts* are units used as a measurement of *power*. Here is the scientific definition.

***Power* is the rate at which work is being done.**

Another way to think of it:

***Power* is the *rate* at which *energy* is being transformed.**

The 100-watt bulb is brighter than a 60-watt bulb because it transforms more electrical energy to light energy in a given amount of time.

Using **P** for power, **W** for work, **T** for the time during which the work is being done, the equation for power is:

$$P = \frac{W}{T}$$

Power is measured with different kinds of units, depending on the type of energy that is being transformed. Watts can describe *any* power use, but it is most often used for electric power. Fuel burning engines and large electric motors are often rated in units of *horsepower*. Until the 20th century much of the heavy work in the world was done by horses and other animals, so it was natural to think of energy use in terms of the work a horse could do.

Questions:

5.2 Can you think of instances in the United States, and around the world, where animals are still used for their power?

5.3 How many 100-watt light bulbs would have the power equivalent of a 40-horsepower car? (One horsepower is 746 watts.)

5.4 What power did a newlywed husband have to generate to lift his new bride the distance of one meter in one second? The bride weighs 500 newtons and suppose 1 newton = .22 pounds.

5.5 Remember the problem on page 19: If an automobile has expended an amount of energy equivalent to 1,200,000 joules of work, and to propel the car the engine is exerting a force of 600 newtons, how far has the automobile traveled? Now, if it took the automobile two minutes to travel that distance, what was the power of the automobile?

Sample Problem

How much power does it take to lift a book from the floor to a shelf at a height of two meters in two seconds, if the book weighs the equivalent of 0.25 newtons?

Solution:

P = W / T

W = 0.5 joule (see page 19)   T = 2 seconds

P = 0.5 joule / 2 seconds = 0.25 joule/seconds = 0.25 watt

A unit of work common in science is a joule. One joule is equivalent to the work needed to move an object a distance of one meter while applying a force of one newton. If you work at a rate of one joule every second, you are expending power at a rate of 1 watt. In other words, 1 joule/second = 1 watt

Volts & Amps

The power of electricity can be compared to the power of running water. Imagine the tremendous power of a large waterfall like Niagara Falls. Its power can turn a dozen huge electrical generators at once.

The power of Niagara Falls depends on two factors: the sheer height of the falls, and the vast current of water in the Niagara River. If the current of water were no more than a trickle it wouldn't have much power at all, no matter what height it fell from. If the height of the falls were just an inch or two it wouldn't have enough power to turn even one turbine. The height of the water relates to its potential energy. The current of water converts that potential energy to kinetic energy as the water drops.

In a wire that carries electric power there is a current, but it is not a current of water. It is a current of *electric charge*. Like water, electric charge can flow in a current. The flow of electric current is measured in *amperes* (often called amps).

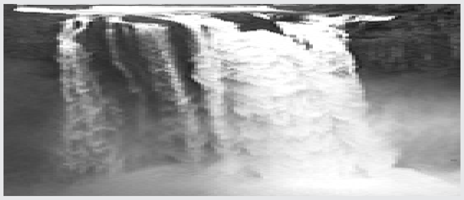
Like water, electric charge can have potential energy. The potential of electric charge is measured in *volts*. The voltage of a typical flashlight battery is 1.5 volts. Put two of those flashlight batteries together end to end and you have 3 volts. The electric charge that flows around a 3-volt circuit does twice as much work, or transforms twice as much energy as the electric charge in a 1.5 volt circuit.

Most electric appliances are designed to run only at a particular voltage. Standard outlets in the United States are kept at 110V to 120V. Some high-power appliances, such as electric clothes dryers, run on 220V.

Three Waterfalls
Each one is a different height.
Each one has a different current.
They all have the same power.

High Potential
Low Current

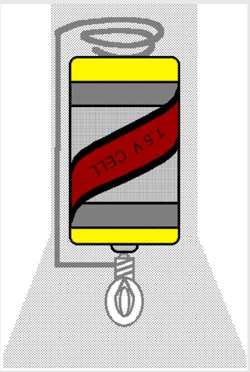
Medium Potential
Medium Current



Low Potential
High Current

Question 5.6
Is there a 220V outlet where you live?
In which room?
For what appliane(s)?

Electrical Energy and Power



In the simple circuits of a flashlight, electric current makes a trip from one end of the battery (or batteries) to the other end. The voltage of the battery determines how much work each bit of electric charge does along the way, just as the height of a waterfall determines how much energy is converted as each gallon of water drops to the bottom.

Electrical Energy

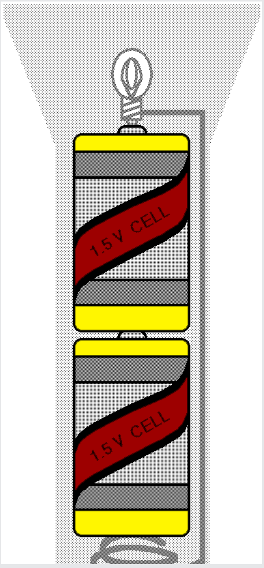
The two flashlights on this page operate at different voltages. Can you tell which one is more powerful? The one with two batteries, right? Not necessarily. Voltage is only half the story. The power depends on the voltage *and* the current, just like the power of Niagara Falls depends on both the current and height from which the water falls.

The power, **P**, of any electrical device, is the product of the voltage, **V**, and the current, **I**.

P = V x I

For any appliance, if you know the current (in amps) and the voltage (in volts), you can use this formula to find its power in *watts* —even if its wattage is not listed on the label. Find the missing values in the table below:

An electric company does *not* charge for power. It charges for energy. Can a 40-watt lamp use more energy than a 1000-watt hair dryer? Yes, if the hair dryer is on for five minutes a day and the light bulb is left on all night.



The energy, **E**, an appliance uses is its wattage, **P**, times the amount of time, **T**, that it is turned on.

E = P x T

If the power is in watts and the time is in hours this formula gives you the energy in *watt-hours*. A 100-watt light bulb shining for one hour will use 100 watt-hours of energy. During a typical month a household uses thousands of watt-hours of electricity so an electricity bill generally lists electricity use in kilowatt-hours.

1 kilowatt-hour
= 1,000 watt-hours
= 3,600,000 joules

Question 5.7
What values would go in the blank cells of this table?

APPLIANCE	VOLTAGE	CURRENT	POWER
Laser printer	115 volts	7 amperes	
Digital clock	120 volts		5 watts
Food processor		6 amperes	690 watts
Heating pad	120 volts	0.4 amps	
Hair dryer	120 volts	12.5 amps	

Electrical Conductors and Electrical Resistance

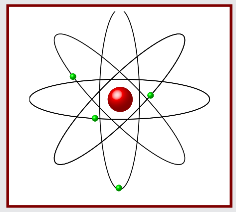
In many materials all the electrons in each atom are bound tightly to the nucleus. Such materials are called *insulators*—they do not allow electricity to flow easily. Glass, rubber, and plastic are good insulators. Materials that are good *conductors* of electricity have electrons that are not bound to any particular atom. The electrons flow easily among the atoms in the solid. Silver is the best conductor, but copper and aluminum are used more often in wiring.

Can you guess why?

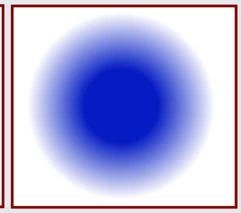
In a conductor, as electrons flow, they bump into atoms, causing them to jiggle and heat up the conductor. This effect is called *resistance*. Resistance transforms electrical energy into heat energy. In your home, there is a limit to how much current the wires can safely carry without danger of overheating and causing fires. *Circuit breakers* and *fuses* are devices that switch off the electricity if the current rises above a safe level.

Two Ways to Picture an Atom

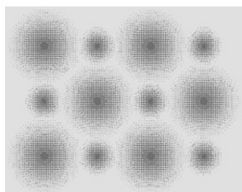
In an atom, positively charged protons and neutrons are bound together in the nucleus at the center. Negatively charged electrons occupy the rest of the space in the atom.



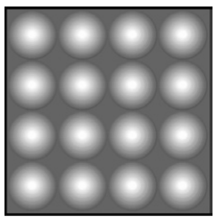
The "planetary" model is often used to illustrate an atom. The size of the nucleus is drawn a hundred thousand times larger than it is.



In modern physics we realize the exact position and path of an electron can never be known, so electrons may be depicted as a kind of cloud around the nucleus. In this drawing, the electron cloud of a helium atom is enlarged about one hundred million times. At this scale the nucleus is an unprintable small dot.



Electrons will not flow in this salt crystal.



Some electrons move freely in this arrangement of copper atoms.

Investigation

Fuses and Circuit Breakers

Find out where the fuse box or the circuit breaker box is where you live.

Some appliances depend on resistance for their operation: the burner of an electric stove, a toaster, and an incandescent light. However, in the cables that carry electricity, resistance causes loss of electricity, which is undesirable.

Measuring Resistance

Electrical resistance is measured in *ohms*. The amount of resistance, **R**, in ohms, is defined in terms of the voltage, **V**, and current, **I**, by the formula:

R = **V** / **I**

This is known as *Ohm's Law*. Example: If you double the voltage across a wire, the current through the wire will double.

Units to use in the formula:

Resistance **R** is in ohms

Voltage **V** is in volts

Current **I** is in amperes

Sample Problem

A home toaster is rated to operate with an electric current of six amperes on a 120 volt electric line.

What is the resistance of the toaster's heating elements?

Solution:
R = V / I = 120 volts / 6 amperes = 20 ohms

Question 5.8 What are the resistances of these appliances?

A laser printer for a computer: 115 volts; 7 amps

Digital alarm clock: 120 volts; .04 ampere (40 milliamperes)

Food processor: 115 volts; 6 amperes

Heating pad: 120 volts; 0.4 amperes

Hair dryer: 120 volts; 12.5 amperes

Power Losses in Transmission Lines

The high voltage transmission lines used to get electric power from the power plant to the neighborhoods where the electricity is used are necessary to minimize losses of energy in the wires due to the wires' electrical resistance. For a wire of resistance **R**, with a current **I** flowing through it, the power loss P_{Lost} can be calculated by this formula:

$$P_{Lost} = I^2 \times R$$

Remember: Twinkle, twinkle, little star.
Power equals I squared R.

Units to use in the formula:

Resistance **R** is in ohms

Power **P** is in watts

Current **I** is in amperes

The less current that flows, the less power is lost. So how can an electric company deliver high power with less current? Remember that power is voltage times current, so the same power can be delivered using low current at high voltage or high current at low voltage. Which alternative gives the least power loss from resistance in the wires? From the power loss formula above, the answer is obvious: minimize the current and maximize the voltage.

Sample Problem

In the problem of the home toaster on page 53, what was the power given off as heat in the toaster's heating elements?

Solution: The toaster's current use was six amperes and we calculated the resistance to be 20 ohms. $P_{Lost} = I^2 \times R$ = (6 amperes)^2 x 20 ohms = 720 watts

Question 5.9

Standard long distance power lines carry electricity at 230,000 volts. Suppose the resistance in a particular stretch of power transmission line is 100,000 ohms and current is flowing at 0.1 ampere.

What is the power loss in the transmission line?

Question 5.10

Some long distance power lines operate at 765,000 volts.

How much less power would be lost in a 100,000 ohm line operating with a current of .03 ampere at 765,000 volts as compared with .1 ampere at 230,000 volts?

Superconductors-No Resistance

In 1911, H. Kamerlingh-Onnes assigned his student assistants to find out how the electrical resistance of metals changed when they became very cold. When the students reported that some materials had absolutely no resistance at extremely cold temperatures he sent them back to figure out what mistake they had made. There was no mistake. They had discovered *superconductors*.

Superconductors have been used in devices such as experimental computers and medical equipment. Using superconductors in long distance power lines, electromagnets, or motors might be a way to save energy if it were not for the problem of refrigeration. Keeping superconductors cold enough uses energy.

Researchers have made many breakthroughs in superconducting technology but scientists still do not fully understand how they work. Further research may show ways to save energy with these materials.

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/9eu.html. We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

6. Energy in Society

The Big Picture

The flow chart on the next page may look complicated, but it's really not difficult to interpret. It provides THE BIG PICTURE of how the United States uses its energy resources.

The top section of the chart shows the major **primary sources** that humans tap for energy. The amounts of energy that the United States used in 1997 is given in the equivalent energy of quads (1 quad = 170 millions of barrels of oil). Notice that electricity is not counted as a primary source. That is because it is converted from other sources. The conversion to electricity is shown in the box near the middle of the diagram.

The bottom box shows the sectors of society that are the **end users** of energy. The *transportation sector* includes the shipping of cargo, mass transportation, and personal automobiles. The *industrial sector* includes construction, manufacturing, and agriculture. The *commercial and residential sector* includes homes, offices, stores, schools, and hospitals.

Let's start to untangle this chart by following the widest path—the one for crude oil. What happens to the 27 million barrels of oil that are withdrawn from the ground every day? Two million barrels are either used to run equipment in oil refineries or are lost through heat in oil refineries. Five million barrels are used in large power plants to produce electricity. Four million barrels are used for non-energy purposes, such as making asphalt for roofing and street paving, and making plastics. The rest is used directly by end users: 11 million barrels are burned as fuel in cars, trucks, ships, and airplanes; four million barrels are burned by industries; and one million barrels are burned in residential and commercial buildings, mostly to provide heat.

The chart has boxes on the left for all of the energy resources that never make it to the energy users. Add up all the numbers to see how many million barrels of oil this loss comes to each day. It would be simple to say that this is wasted energy, but that is not necessarily true. Some of these energy resources are used as ingredients for materials that do not provide energy but are otherwise useful. Some energy is used to refine or deliver energy.

Answer the following questions by following different paths in the flow chart.

Question 6.1
What happens to the energy in coal that is mined every day?

Question 6.2
What happens to the energy in natural gas?

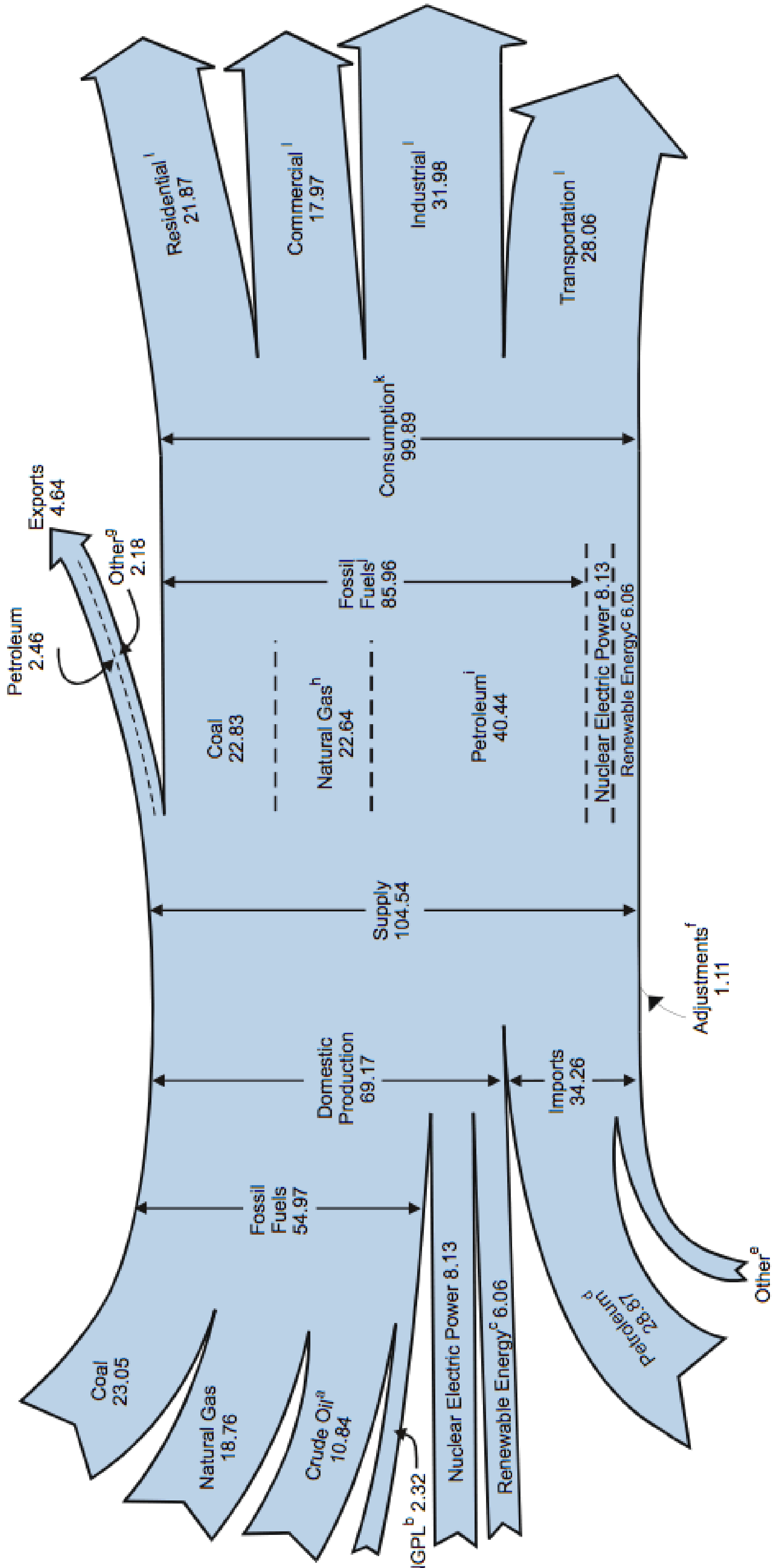
Question 6.3
For the electricity that is delivered to end users, what per cent is lost in transmission lines?

Question 6.4
How much energy in the form of electricity is delivered to the end users daily and how much primary source energy is needed to produce that electricity?

Question 6.5
What might be some "non-energy uses for coal and natural gas?"

United States Energy Flow from Source to End Use

Numbers are QUADS (quadrillion BTU). Year: 2005.



a Includes lease condensate.
b Natural gas plant liquids.
c Conventional hydroelectric power, wood, waste, ethanol blended into motor gasoline,geothermal, solar, and wind.
d Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.
e Natural gas, coal, coal coke, and electricity.
f Stock changes, losses, gains, miscellaneous blending components, and unaccounted-forsupply.
g Coal, natural gas, coal coke, and electricity.
h Includes supplemental gaseous fuels.
i Petroleum products, including natural gas plant liquids.
j Includes 0.04 quadrillion Btu of coal coke net imports.
k Includes, in quadrillion Btu, 0.34ethanol blended into motor gasoline, which is accounted forin both fossil fuels and renewable energy but counted only once in total consumption; and 0.08 electricity net imports.
l Primary consumption, electricity retail sales, and electrical system energy losses, which areallocated to the end-use sectors in proportion to each sector's share of total electricity retail sales. See Note, "Electrical Systems Energy Losses," at end of Section 2.

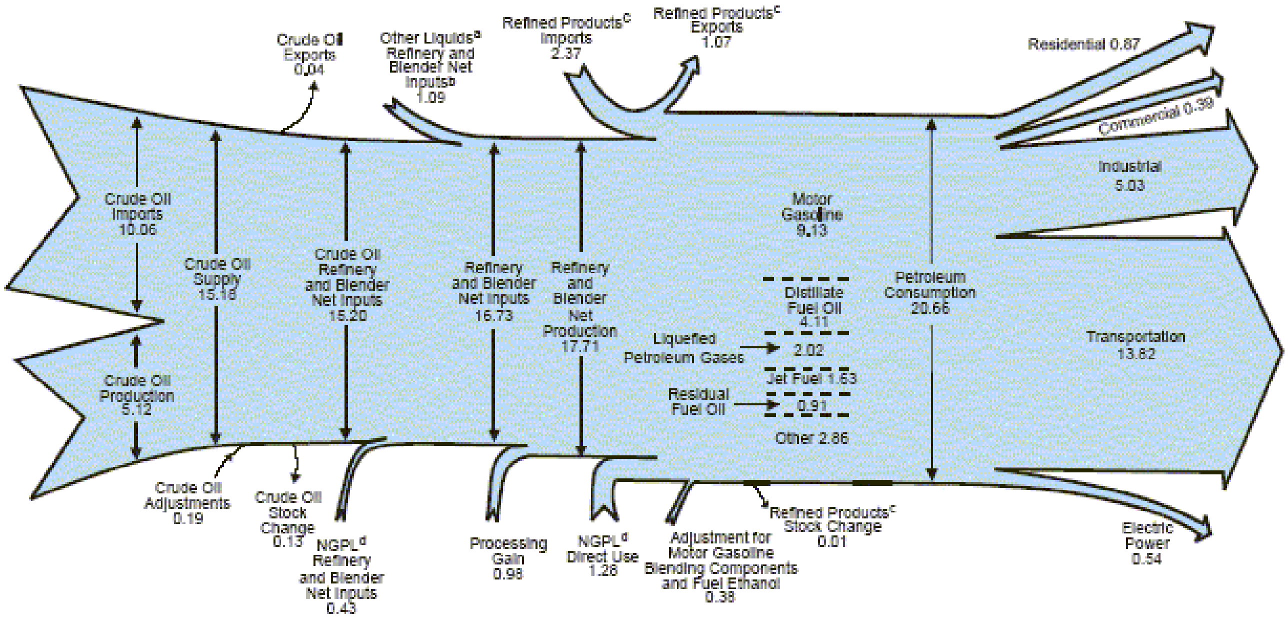
Notes:
- Data are preliminary.
- Values are derived from source data prior to rounding for publication.
- Totals may not equal sum of components due to independent rounding.

Sources: Tables 1.1, 1.2, 1.3, 1.4, and 2.1a.

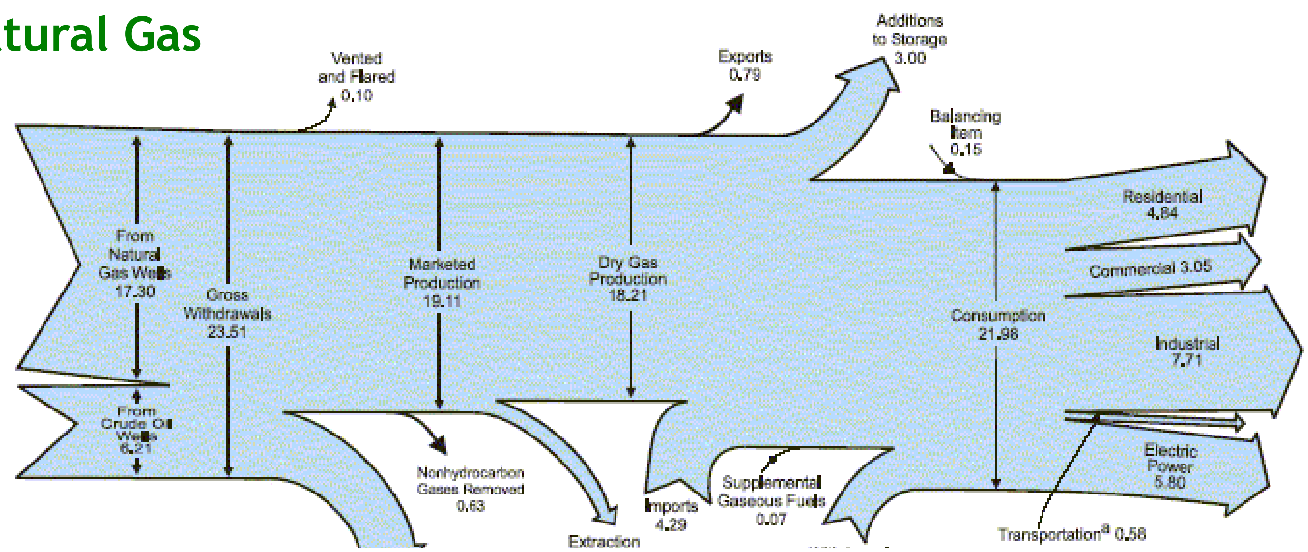
Source: http://www.eia.doe.gov/aer/ and http://www.eia.doe.gov/aer/diagram1.html

Source (2005): http://www.eia.doe.gov/aer/

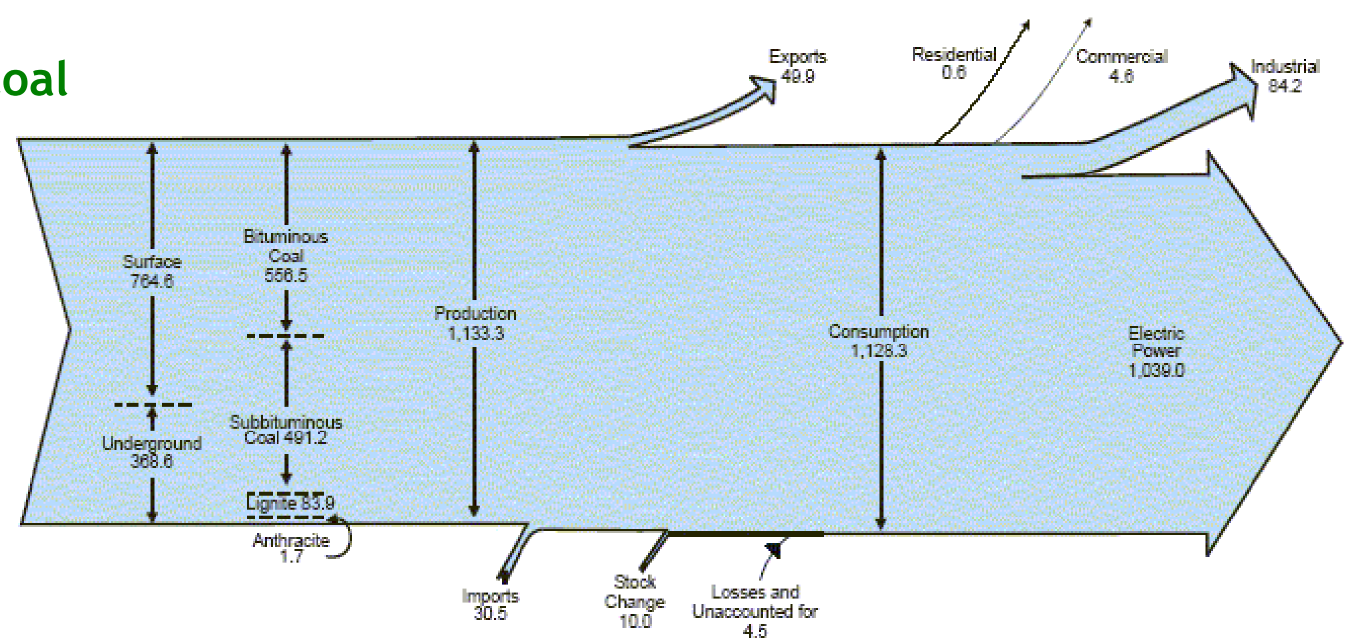
Petroleum



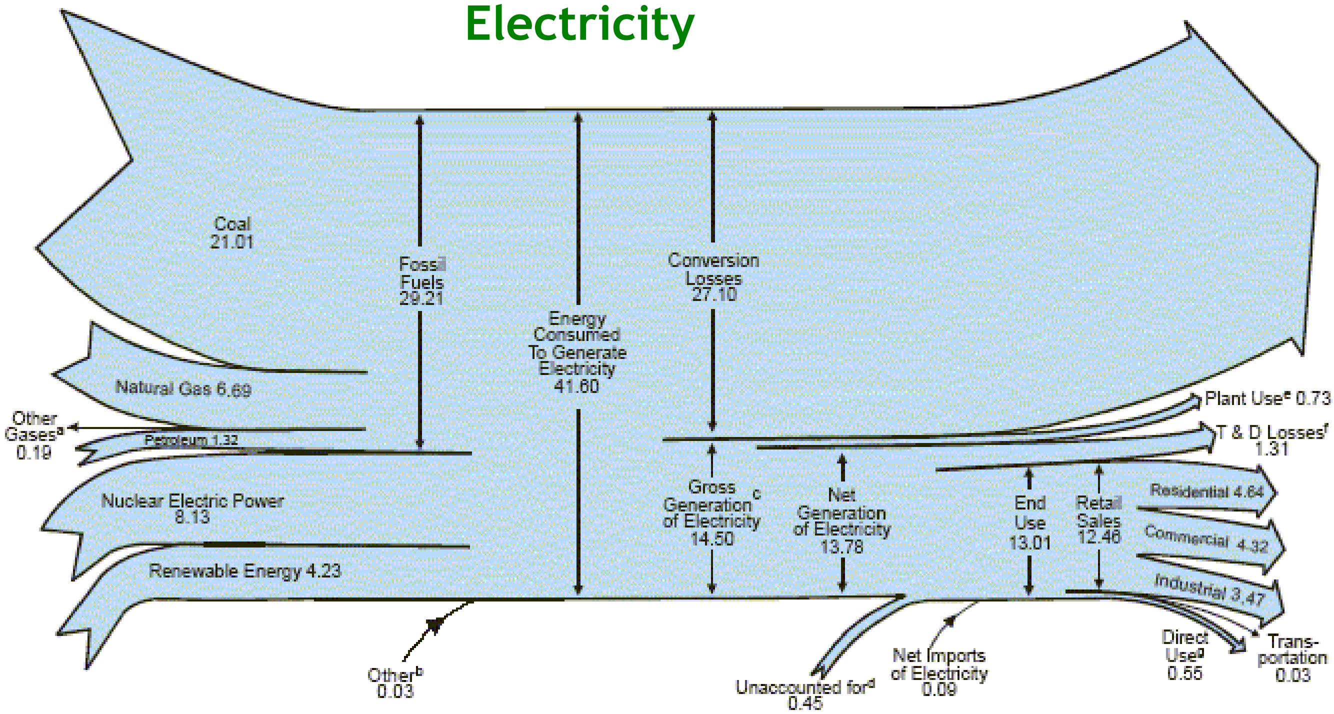
Natural Gas



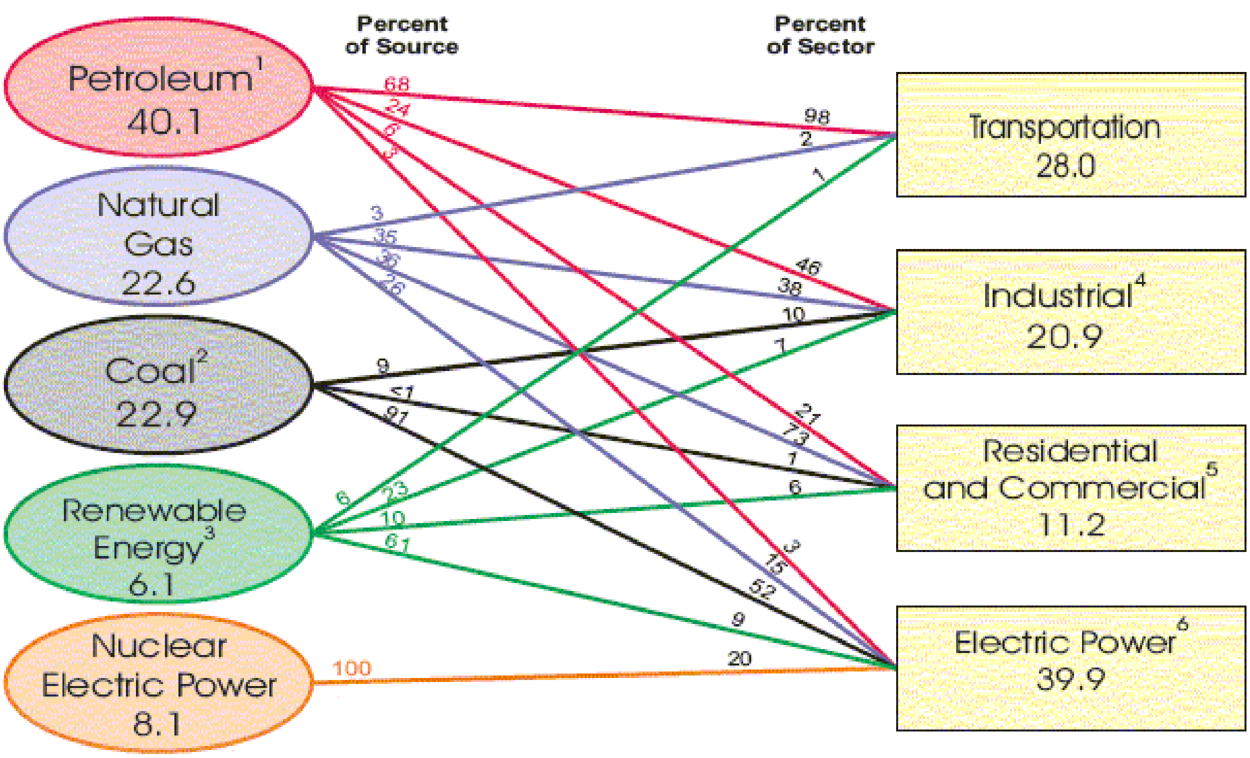
Coal



Electricity



Source (2005): http://www.eia.doe.gov/aer/



The real waste is hidden in various places on the chart. Energy is often wasted by the ones who use it, more than the ones who find it and deliver it. Finding the waste and curtailing it is a job in itself.

Energy Conservation—Becoming Energy Conscious

Meet Mary Ann Piette. She is a staff scientist at Lawrence Berkeley National Laboratory (LBNL). Her job is to analyze the energy performance of buildings. Piette tells us her interest in energy issues was sparked by a utility company speaker who gave a talk at her high school.

Mary Ann Piette in her office at the Lawrence Berkeley National Laboratory in Berkeley, California.

Piette became a physical science major at the University of California at Berkeley. She was cultivating an interest in astrophysics when her path was changed by a course that she took on the physics of energy conservation taught by Arthur Rosenfeld of LBNL. Rosenfeld demonstrated, in a very dramatic way, what was wrong with the "more is better" philosophy of energy use.

Rosenfeld's class showed that if the world continues on its present course it will use more and more resources at an ever-increasing rate. Not only is the world's human population growing rapidly—adding the equivalent of the population of Mexico every year—but the industrialization of countries such as China and India means that the number of fuel-burning power plants, factories, cars and trucks, and large public buildings are growing even faster than the world's population. The problem with this growing demand for energy is its impact on the environment. In Rosenfeld's view, we cannot continue to extract more and more of the world's resources, and transport them on tankers, trucks, trains, and through great pipelines without seriously affecting the environment.

Some people suggest that new sources of energy or improved nuclear power plants would solve our problems. But scientists and engineers have worked on these problems for years with only limited success. Others suggest we substantially change our life-styles: not use cars as much, and put on lots of sweaters rather than turn on the heaters. But Rosenfeld suggested a very different and simple solution—conservation. If we could find new ways to meet our needs by using fewer resources, and if everyone on the planet adopted these new ways, we could at least postpone environmental problems until new sources of energy are developed.

Piette was so inspired that she changed her main career path. She took courses on solar and wind energy systems, and eventually earned a Master's degree in mechanical engineering. This expertise allows her to design ways to conserve energy, save money, and benefit the environment.

Mary Ann Piette examines rooftop solar water heaters.

The work of scientists and engineers like Piette allows everyone to participate in energy conservation. Included on the following pages are some of the material in her course work that convinced her energy conservation is a good thing to do.

Energy Use and Benefits to Society

Some things are easy to describe with numbers. Some are not. Consider the following conversation:

"How much gasoline did you use on your trip to the lake?"

"Five gallons exactly. I kept careful track."

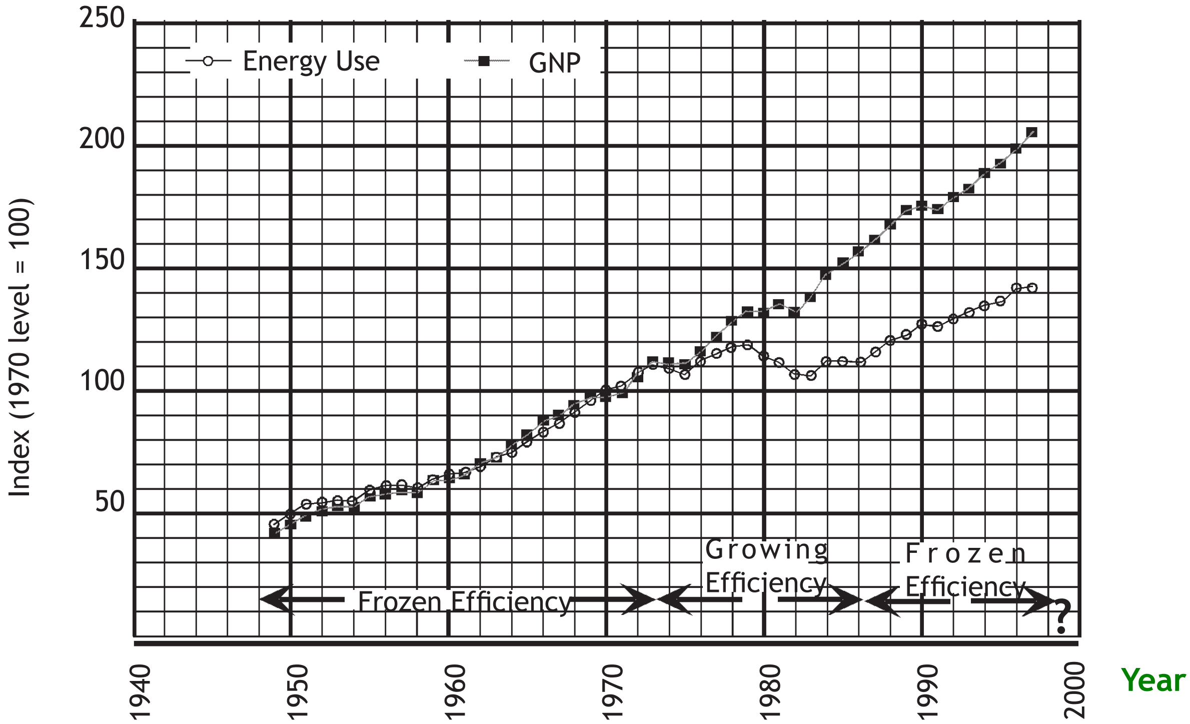
"And exactly how much did you enjoy it?"

"I enjoyed it exactly – Wait! How can I answer that?"

The person who took the trip had no problem describing the amount of energy she used. She just said the number of gallons of gasoline. It is trickier to put a number on enjoyment, happiness, or well-being.

If we are going to look at the impact of energy conservation on a society we need some way to describe the well-being of society. One measure of the economic health of society is called the *Gross National Product* or *GNP*. The GNP is the total dollar-value of all the goods and services produced by a society in a year.

U.S. Primary Energy Use and GNP from 1949-1997



The information on this graph is indexed, *meaning that all the numbers were recomputed so that GNP and Energy Use equal exactly 100 in the year 1970. Energy use can never actually equal GNP because one is a measure of energy and the other is a measure of dollar value.*

Indexing allows us to compare the different quantities as they grow and change. To find the latest data see the Global Systems Science website, http://lhs.berkeley.edu/gss/uptodate/9eu.html Chapter 6.

Question 6.6
What is the significance of the comparative slopes of the lines in this chart?

Question 6.7
Does the graph show growth in efficiency completely stopped after 1986?

Here's how Rosenfeld compared the use of energy with the GNP. The graph on this page shows the Gross National Product (GNP) of the United States during the years 1949 to 1997. The steady rise in GNP during most of the time indicates a strong healthy economy. On the same graph is a line showing the growth of primary energy use in the United States. Primary energy use is the total amount of energy resources—fossil fuels, nuclear, and hydroelectric—used in a year. Rosenfeld points to this graph as a powerful piece of evidence in support of his belief in the value of conservation as a way out of the energy-environment dilemma.

A common notion is that a healthy economy depends on the progressive use of larger and larger amounts of energy. Examine the graph during the period from 1949 to 1973. The use of primary energy resources rose fairly steadily. So did the GNP. Economic growth and energy use went hand in hand. The efficiency of energy use, the value of goods and services produced for each unit of energy used, did not change during this period. It was a period of frozen efficiency.

By 1973 the United States had become dependent on cheap sources of oil from the Mideast and South America. That's when OPEC, the Organization of Petroleum Exporting Countries, decided to raise prices. OPEC included all of the countries we purchased oil to fill the tankers and pipelines needed to fuel power plants and factories in this country.

The result was chaos in the world economy. Increased oil prices meant higher prices at the gas pump.

It cost more to transport goods to market, and it cost more to produce electricity to run factories. The prices of just about everything increased, in nations around the world.

Industry leaders responded by cutting down on energy use. They found ways to produce goods with less electrical power. They figured out how to transport goods to market with less fuel. Car manufacturers figured out how to build cars that traveled more miles on a single gallon of gas. Consumers responded by buying the fuel-efficient cars, purchasing refrigerators that used less electrical power, turning off unnecessary lights to reduce their high energy bills, and investing in solar water heaters and other energy-saving devices.

The result can be seen by examining the period between 1973 and 1986. Energy resources used in the United States stayed fairly constant while GNP continued to increase. Efficiency was growing. ***This critical period in recent history, 1973-1986, challenges the notion that economic growth means a society has to use more energy.*** The economic health of the country as a whole, including jobs for workers and products for consumers, can be sustained without increasing our use of energy resources.

The growth of energy efficiency continued until the mid 1980s when two things occurred. Without a growing demand for oil, OPEC dropped its prices. With cheaper oil, there was less incentive to conserve energy. The was also a changing philosophy in government. Many energy-saving programs ended. This was symbolized by the removal of the solar water heaters from the White House roof that had been installed during the energy crisis.

The graph shows GNP continued to rise after 1986, but the period of growing efficiency ended. Energy use began to climb again in step with GNP. A new period of frozen efficiency had started. The rising popularity of Sport Utility Vehicles (SUVs) that are relatively inefficient in use of fuel symbolizes the return to frozen efficiency.

Conservation and Efficiency in Industry

People who work in industry understand the tremendous value of a few pennies saved. The reason is simple. If a factory produces 100 million widgets, then a savings of even half a cent on each widget adds up to an extra half million dollars in profits.

Turning raw materials into refined materials such as glass and metal takes lots of heat. Shaping these materials into finished products uses more heat. Heat is needed to synthesize the thousands of chemicals that go into plastics, paints, paper, fertilizer, and so on. Factories burn huge amounts of fossil fuels for these purposes. It is not surprising, therefore, that industrial engineers must be knowledgeable about the science of *thermodynamics*—the study of heat.

A law of thermodynamics states: no machine can be 100% efficient. There will always be some energy that is "wasted." However, engineers can find ways to use the "wasted" heat, just as they would any raw material that doesn't find its way into the final product. Imagine, for example, a factory in Northern Minnesota that makes glass bowls and cups, and is in danger of closing because of low profits. A clever engineer might install hot air ducts so that "waste" heat from the furnace can be used to preheat chemicals on their way into the furnace for processing. Or, the offices might be relocated to the second floor so that air heated by the furnace can float upwards to heat the offices by convection, saving thousands of dollars per month on utility bills.

So-called "waste heat" from factories and power plants can benefit the surrounding community. In the practice called *cogeneration*, heat from industry is distributed in the form of steam or hot air for nearby homes and businesses.

How Everyone Can Help Industry Conserve

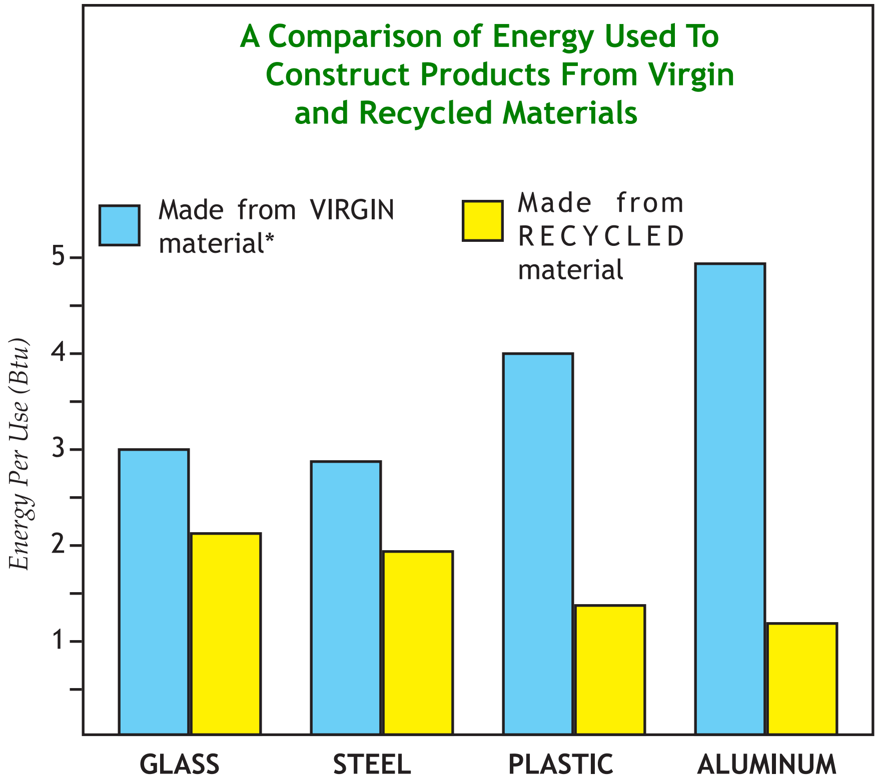
One way that industries have reduced their use of energy is by using fewer but better materials in their products. Sheet metal in the body of a car, for example, is engineered to be both strong and light. Besides saving energy costs in producing the car, it increases fuel efficiency. Other industries are finding new ways to package products using smaller amounts of paper and plastic.

Whether or not industry continues to produce such products depends on us—the consumers. Over the past 50 years, Americans have consumed more resources than the rest of the world in all previous history. Consumers can encourage industry to conserve by purchasing fuel-efficient cars, and choosing products that are not packaged with unnecessary amounts of paper and plastic.

Industry can produce fewer new materials in their products, or, with the help of consumers, industry can save even more energy by reusing old materials. Each year Americans throw away enough Styrofoam cups to circle the Earth 436 times. Every hour, 2.5 million plastic bottles are used. Here are some ways to encourage industry to conserve.

Recycling

Making enough aluminum for one soda pop can takes about five Btu. Take that soda pop can and throw it in the trash and those five Btu have done all the good that they will ever do. Send that can back to the factory and for a little more than one Btu it can be made into a new can. Used aluminum is an energy source, not because it is a fuel, but because it prevents the need for using fuels to create new aluminum. The same principle applies to other metals as well as glass, plastic, and paper, although, as shown on the graph on the next page, the energy saved by recycling these materials is different.






** Material that has never been used before is called* **virgin** *material. Virgin material comes from natural sources. Glass is made from sand. Virgin steel comes from iron ore. Virgin aluminum is made from a mineral called bauxite. Virgin plastic is produced from chemicals in petroleum and other sources. Data for plastic on the graph is an estimate. Recycled plastic bottles are usually made into construction materials or outdoor furniture and not new plastic bottles.*
Source: Mark H. Ross and Daniel Steinmeyer, "Energy for Industry," Scientific American, September, 1990, page 96.

Reuse

Sometimes you don't need to melt down a glass bottle to get a new glass bottle. Just wash the old one. Dairies and beverage bottling companies have been doing this all along. Is milk delivered in bottles where you live? Sometimes it is available in a reusable bottle in stores. While you are at the store you can save energy by reusing a bag for your groceries.

Question 6.9
When you throw away a soda pop can how many Btus go with it?

Question 6.8
Many people use the terms "recycling" and "reusing" interchangeably, but they are different.

What is the difference and which one saves more energy?

Tracking Down Electrical Energy

"We really have to bring our electric bills down! You would save us money if you cooked that hot dog in the microwave instead of the frying pan."

"How about this. I'll keep frying my hot dogs and we'll save by having you stop using the blow dryer every time you wash your hair."

"I'll keep using the dryer, and we'll save by turning the TV off once in a while."

"I wonder if we could save by not having the stereo playing so loud all the time?"

"How about unscrewing that light bulb that comes on when you open the refrigerator?"

How much energy do different appliances really use? You can track down the answer if you know the power of the appliances and how much they are used. Many of them have the power in watts printed right on them. If the wattage is not listed, there may be other ways to track down the power. But first, you have to know a little more about measuring electricity.

Measuring Electrical Energy

Somewhere on your house or apartment building there is a meter that keeps track of the electrical energy you use. Schools, public buildings, stores, and other businesses have these meters too.

The most common kind of electric meter, like the one pictured on the left, has a row of dials with pointers that slowly turn as your household consumes electrical energy. Remember, electrical energy does not disappear when it is consumed. It is transformed into other kinds of energy. A lamp transforms electrical energy into light. A toaster transforms it into heat.

Home Electric Meter
This style of electric meter has been in use by power companies for decades to determine how much electrical energy is used by every house, apartment, and public building in the country. It is made to be checked each month by a meter reader. As computers and automation become more widespread, you can expect changes in the look and operation of electric meters.

Investigation

Electric Metering

The purpose of this investigation is to see how your home electric meter responds to energy use in your home. Find the electric meter at home. The pointers on the dials move very slowly, but most meters have a disk that turns fast enough that you can easily see it spin. If your meter is the kind with a spinning disk, try these simple experiments.

Go through your home and turn off as many of the electrical appliances as you can. It is best to do this during daylight hours. Also, check with the other people at home to make sure you do not turn off the oven while the souffle is cooking or otherwise interfere with their use of electricity. It will probably be okay to unplug the refrigerator for a few minutes. Now check the meter.

- *Is the disk turning more slowly?*
- *Did you make it stop? If not, can you think of appliances in your house that may still be using electricity?*

Now you can plug in the refrigerator, reset all the clocks, make sure the pump in the fish tank is working again, and do whatever else is needed to get your household back in order. Another quick experiment may require a helper. Watch the electric meter while someone turns a light on and off.

- *Can you see the meter speed up when the light goes on?*

Try it with a higher wattage (more powerful) appliance such as a toaster, hair dryer or vacuum cleaner.

Question 6.10
What happens to the energy that runs a computer, a clock, or a vacuum cleaner?

Investigation

What Are We Paying For?

Determine the costs of various home uses of electricity, learn what your biggest electricity eaters are, and find out where the money goes.

Materials

- A household electric bill for the month

Strategies for Investigation

1. Prepare a table with five columns like the sample below. In column 1 list all the electrical appliances in your home. Group the appliances in categories such as heating, lighting, food preparation, washing clothes, power tools, entertainment. Make the list as complete as you can.
2. In column 2 list the power rating, in watts, of each device. Most of them have a power rating label on the back or bottom. If the rating is given in amperes for a wall-socket appliance, you must multiply the ampere rating by 120 volts to figure out the power rating in watts.

> The energy
> **E (in watt-hours)**
> an appliance uses is its wattage **P (in watts)** times the amount of time **T (in hours)** it is on.
> **E = P x T**

> The power
> **P (in watts)**
> of any electrical device is the product of the voltage **V (in Volts)** and the current
> **I (in amperes)**.
> **P = V x I**

Sample Chart Of Typical Electrical Costs in One Month

Electrical Appliances	*Power Rating (in watts) P*	*Daily Time (in hours) T*	*Daily Energy (in kwh) E = (PxT)/1000*	*Monthly Cost (in dollars) Cost = (ExR)x30*
Clock	*2*	*24*	*0.048*	*0.14*
Bathroom and bedroom lights	*(60 watts x 6) = 360*			
Living room lights	*100*	*4*	*1.44*	*4.32*
Porch light	*18*	*5*	*0.5*	*1.50*
Hot Water Heater	*4,000*	*12*	*0.216*	*0.65*
TV	*300*	*3*	*12*	*36.00*
Vacuum cleaner	*800*	*2*	*0.6*	*1.80*
Clothes washer		*0.25*	*0.2*	*.60*
Clothes dryer				
...				
...				

SAMPLE

> *If your home's water heater is gas-fueled, its cost does not appear on the electric bill. If your home is rented, you may not pay the direct cost of heating water. How is that cost passed to the people in your home?*

3. In column 3 estimate the average number of hours per day the device is on. A clock would be on all the time. Some devices like a heater or refrigerator are plugged in all the time but switch on and off automatically. Three hours a day is about right for most household refrigerators. For items that are not used every day, estimate the use for a week and divide by 7.

4. Column 4 is for the energy used by each device each day. Find the energy by multiplying the power (P) and the time (T) for each appliance. That gives you energy in watt-hours. Divide by 1,000 to get kilowatt-hours.

5 Column 5 is for the monthly energy cost. Find out the cost or *rate* (R) that you pay per kilowatt-hour by looking at an electricity bill. For each appliance, multiply the energy usage by the cost per kilowatt-hour to obtain the actual cost of each item per day. Multiply by 30 to get the monthly cost.

Analysis of Results

1. Add up the costs for the appliances you listed to get an idea of your monthly electrical costs. Does it nearly match your electric bill? If not, modify your estimates until you have a reasonable idea of costs for each category of energy use.
2. Which items and categories of appliances were the biggest electricity eaters? Display the results as a bar graph or a pie chart. You need not include each small item separately, for instance all light bulbs and lamps can be lumped together.
3. Based on your analysis, can you make any recommendations about how to save money on energy costs?

Investigation

Power Failure

The light goes out unexpectedly. Did the light bulb burn out? A peek out the window shows that all the lights in the neighborhood are out. Earthquake? Lightning? Flood? Equipment failure? Human error? All of those factors can lead to electric power outages. Some outages last for moments, some much longer. Imagine a major disaster that leaves your town without electric power for a whole week.

- *How would your life be different each day?*
- *What conveniences would you do without?*
- *What energy sources would you use in place of electricity?*

Write a story about "A week without energy," possibly in the form of a diary or journal. The story should tell about how your life was disrupted by the loss of electrical power, and how you coped with it.

Conclusion

The energy crisis of the 1970s showed that people can conserve without a decline in the Gross National Product. Some energy-saving strategies require changes in our habits. Recycling, for example, requires you to be conscious of the materials you use and where they go when you are done with them.

The next three chapters discuss how energy is used in lighting, heating, and cooling, and transportation. You will read about several strategies for saving energy in each of these areas. As you come across each energy-saving strategy consider the following questions:

- *Am I already doing this? Are other people I know doing this?*
- *Would a change in life-style be necessary to save energy this way?*
- *If a change in life-style is necessary, are there other benefits besides saving energy? What are the drawbacks?*

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/9eu.html. We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link: http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

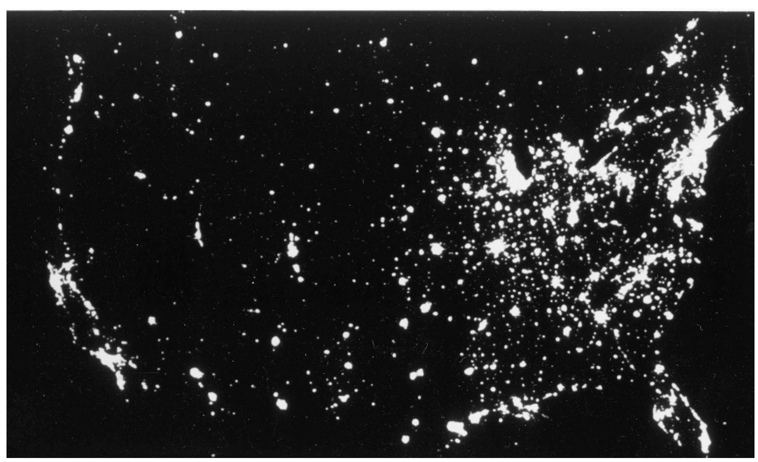
7. Energy for Lighting

An astronomical observatory near Tucson, Arizona, found the quality of its observing conditions seriously impaired by the street lights of a small neighboring community. The lights shone into the sky and illuminated dust particles in the air. Over the years, as the town added more street lights, the quality of images the astronomers obtained through their telescopes declined until they could no longer see the faintest stars against the glare of the background sky.

Rather than giving up, the astronomers decided to find some constructive solutions to their problems. They realized the city lights could not simply be turned off—citizens required the lighting for public safety. However, the astronomers recognized that, from their point of view, there is "good light" and "bad light." "Good light" goes downwards where people need it. "Bad light" goes upwards into the sky. They calculated nearly 50% of the light from the street lights went upwards.

A wealth of information about issues of "good" and "bad" lighting may be found on the website of the International Dark Sky Association at http://www.darksky.org

The astronomers determined they could reduce the amount of light going into the sky by nearly 90% by adding an inexpensive metal reflector around each street light. They further calculated the city would need less electrical energy to provide the same amount of illumination, since most of the light generated would be pointed in a useful direction, rather than being lost to space. In fact, the city's energy savings would, within just a few years, completely pay for the one-time cost of installing the metal reflectors on the street lights. This last point was so convincing, the city agreed to implement the astronomers' plan. It was a "win-win" solution. The astronomers were delighted with darker skies and the city maintained safe street lighting at a lower cost.



The Continental United States Viewed from Space at Night *reveals the tremendous amount of energy we use for lighting. Where is your hometown?* Source: U.S. Air Force satellite.

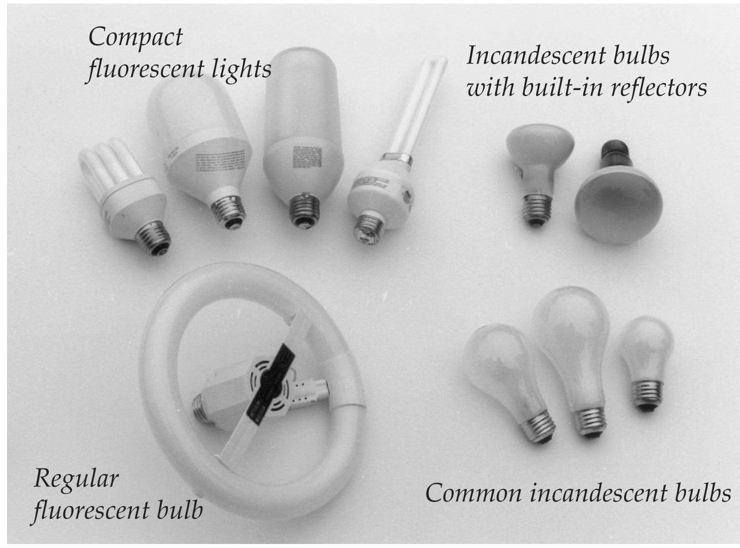
Can you and your household "win" this way? How about your school? What choices do you make when you use electric lighting? Would you like more light shining on this page? Sometimes we are not conscious of our energy-wasting habits. Is there light shining somewhere that you are not using? What qualities would you look for if you were designing a lighting system?

Investigation

Comparing Light Sources

Many types of lights can be found in a hardware store. There are energy-saver incandescent bulbs, fluorescent bulbs, long-life bulbs, low-cost light bulbs, and specialty lights of all kinds. Work with a team to examine a collection of light bulbs. Find the wattage printed on them. If the packaging of the bulbs is available, see what it says. Do any of them claim that they are better light bulbs than the others? Decide on a question comparing the brightness of two bulbs. Here are some examples:

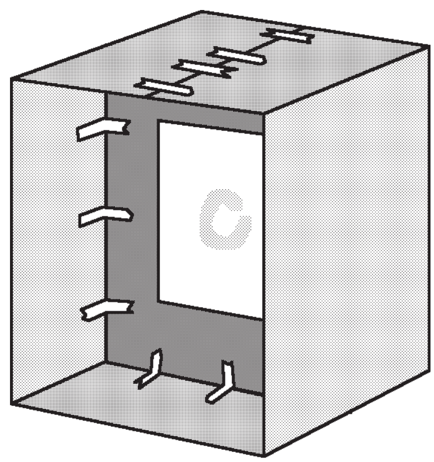
ALL THESE LIGHTS SCREW INTO AN ORDINARY SOCKET



- Are all 75-watt incandescent bulbs alike? A reflector bulb sends out its light differently from a standard light bulb; but they use energy at the same rate. Do they provide the same amount of illumination?
- According to the packaging, a 15-watt compact fluorescent light is supposed to replace a 60-watt incandescent bulb. Is it really just as bright?

When you have decided on a question, build an *oil-smudge photocomparator* so you can compare brightness of lights. Here's how ....

Assemble the Oil-Smudge Photocomparator



The exact size of the parts is not critical. You may need to tape a few pieces of cardboard together for the larger piece.

Materials

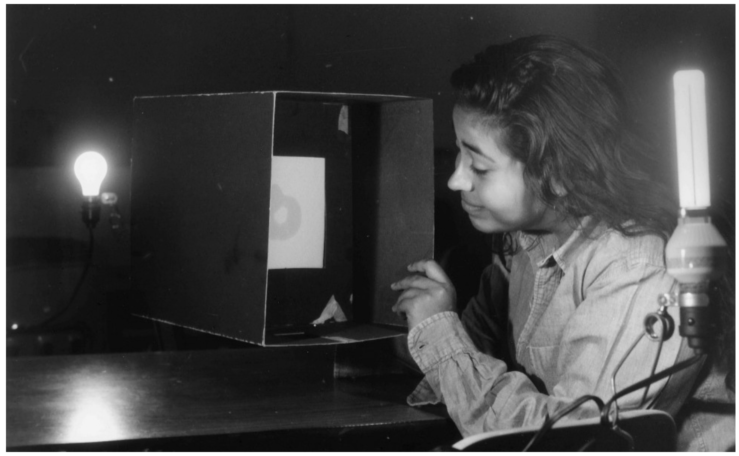
- 1 sheet of white typing paper, 8 1/2" x 11"
- 1 sheet of cardboard, 10" x 12"
- 1 sheet of cardboard, 14" x 44"
- Small amount of oil (mineral oil, baby oil, or cooking oil)
- Scissors
- Masking tape

1. Cut a six inch square hole in the center of the 10" x 12" cardboard.
2. Fold the 14" x 44" cardboard to fit around the 10" x 12" cardboard as shown. Tape it together so it forms a box with open ends. Tape the smaller piece of cardboard inside so it divides the box into two equal sections.
3. With your finger, smear some oil onto the center of the typing

paper in the shape of an "O" about two inches across. Use just enough oil so it soaks into the paper without running. Tape the smudged paper to the cardboard so the oil smudge is in the center of the box.

Test the Photocomparator

Hold the photocomparator so it is between you and a bright light source. Look at the oil smudge. It should appear bright against a darker background. Now, hold the photocomparator so you are between it and a bright light source. Make sure your shadow is not blocking the light. Look at the oil smudge. It should appear dark against a lighter background. Can you explain why?



Whenever the sheet of paper is being illuminated by the same amount on each side, the smudge will be neither lighter nor darker than the background. The smudge may hardly show up at all.

In your experiments, you will shine lights from different sources onto opposite sides of the photocomparator. When the smudge hardly shows up at all you know the photocomparator is receiving equal amounts of light from each side. The distance of each light to the photocomparator will help you determine which light is brighter. You will need to shade your oil smudge from all other lights not involved in this experiment.

Set Up Your Work Space

Additional Materials

- Measuring tape or meter stick
- Oil smudge photocomparator
- Light bulbs to compare
- Fixtures and clamps to hold the bulbs

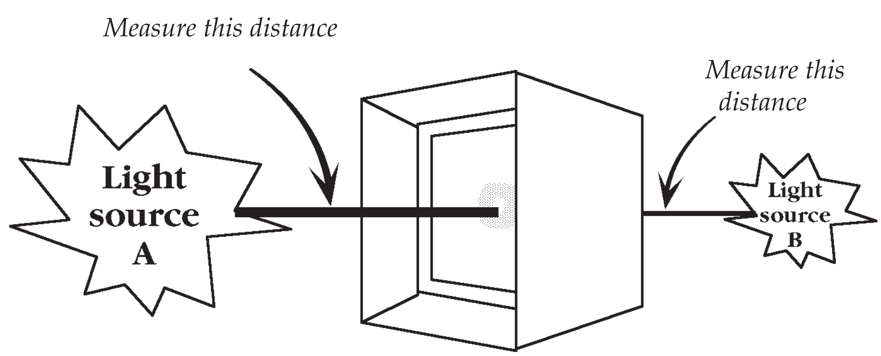
The room you work in should be nearly dark. Be sure the light from one team's bulbs is not shining directly into the photocomparator of another team. It may be necessary to put objects around your work area to block the light.

Set up your two lights at least two meters apart. If there is space, it is better to have the lights three or four meters apart. You will be measuring the distances between the photocomparator and each of the lights.

Gathering the Data

1. On a blank sheet of paper prepare a data table like the one shown on the next page. Fill out the data table with information from the packaging, including cost, wattage, and any comments about the bulbs. If you have no information about the lifetime of a bulb, you can estimate 1,000 hours for a typical incandescent bulb, and 10,000 hours for a compact fluorescent bulb.
2. Have one team member hold the photocomparator between the two lights, A and B. Other team members should stand near lights A and B. They should tell the person holding the photocomparator to move it back and forth between A and B until they agree the oil smudge hardly shows at all. Then measure the distance from each light source to the oil smudge, and write the distances in the table.
3. If there is time, exchange experiments with another team. Make a new data table, and repeat the measurements to confirm the accuracy of each team's data.

Description of bulb	*Distance to photocomparator*	*Cost of bulb*	*Wattage of bulb*	*Lifetime (in hours)*	*Other information*
15-watt compact fluorescent					
60-watt soft light incandescent					



Interpreting the Data

1. *Which light source illuminated the photocomparator the brightest?* By noting which distance is greater, you can tell which light is brighter. The dimmer light will be closer to the photocomparator.

   It is possible to compare quantitatively the brightness of two lights, A and B, with the following formula:

$$\frac{\text{brightness of A}}{\text{brightness of B}} = \frac{(\text{distance to A})^2}{(\text{distance to B})^2}$$

   Use your data to compute the brightness ratio. If one light is considerably brighter than the other, how many times brighter is it?

2. *Which light source is more energy efficient?* Find the ratio of the wattages of the two bulbs by dividing the wattage of bulb A by the wattage of bulb B. You can find out which bulb is more efficient by comparing the brightness ratio with the wattage ratio.

$$\frac{\text{wattage of A}}{\text{wattage of B}} \quad \text{— Compare —} \quad \frac{\text{brightness of A}}{\text{brightness of B}}$$

Sample
*If **A** is 100W and **B** is 20W, the wattage ratio is 100W/20W = 5.*
*If bulb **A** is five times brighter than bulb **B**, the brightness ratio is also 5, so **A** and **B** are equally efficient.*
*But if bulb **A** is just twice as bright as bulb **B**, the brightness ratio is 2. That means that bulb **B** is $2\frac{1}{2}$ times more efficient than **A**.*

If the bulbs are equally efficient the ratios will be equal. If the brightness ratio is *higher* than the wattage ratio, then light A is more efficient. If the brightness ratio is *lower* than the wattage ratio, then light B is more efficient.

Investigation *continued*

3. Did the package make any claims you can evaluate from this investigation? If so, did the bulbs live up to the advertising on the packaging?
4. How do these lights serve your needs? Is there anything about the look of a light bulb, its size, the color of its light, or the direction it casts its light that makes it suitable for some purposes but not for others?
5. Summarize what you did, what you found, and your recommendations in a report.

Efficiency, Costs, and Savings

Suppose you find that a 60-watt incandescent bulb is just as bright as a 15-watt compact fluorescent light. They give similar light and fit the same fixture. For energy efficiency the one with lower wattage is best. But what about the ***total*** cost of the light? A 60-watt light bulb costs about 60¢ and lasts for about 1000 hours. A 15 watt compact fluorescent bulb costs about $12 and lasts for 10,000 hours. Electricity costs, for example, about 10 cents per kilowatt-hour. On the next page are two ways to use this information to compare the costs of the lights. Try them both to see which is the better bargain.

Paybacks from Changing a Light Bulb

Imagine yourself in the hardware store buying a bulb to replace one that burned out. You see the regular incandescent bulbs and you see the compact fluorescent bulbs. One costs less than the other initially, but the other is more energy efficient.

- *Which one will you choose?*
- *What difference will your choice make?*

Image courtesy of www.wikipedia.org

Payback to Households

Suppose you select the more expensive compact fluorescent bulb. There will come a time when the savings on the electricity bill exactly matches the extra money you paid. That is the payback time. At the payback time you have neither gained or lost, as far as money is concerned—except for one thing: The energy efficient light bulb is now paid for, and still working for you. From this point on, all energy savings are also money savings.

Investigation

Method 1: Life Cycle Cost

The *life cycle cost* of a light bulb includes the purchase price and the cost of energy use during its entire lifetime. Since a compact fluorescent bulb lasts 10 times longer than an incandescent bulb, let's compare one compact fluorescent bulb to 10 incandescent bulbs over a 10,000 hour cycle.

INCANDESCENT: Material cost of ten 60 W incandescent bulbs = $________

Energy used over life cycle is 60 W x 10,000 hrs = ________ watt-hours

divided by 1000 watt-hours/kilowatt hour = ________ KW-hours

Operating cost over lifecycle = ________ KW-hours

times $0.10/ kilowatt hours = $________

Total Cost (material cost plus operating cost) of

ten 60-watt incandescent bulbs = $________

COMPACT FLUORESCENT LIGHT (CFL): Material cost of one 15-watt CFL = $________

Energy used over life cycle is 15 W x 10,000 hrs = ________ watt-hours

divided by 1000 watt-hours/kilowatt hour = ________ KW hours

Operating cost over lifecycle = ________ KW-hours

times $0.10/ kilowatt hours = $________

Total Cost (material cost plus operating cost) of one 15-W CFL = $________

	15 watt compact fluorescent	*60 watt incandescent*
Initial cost	$12.00	$ 0.60
Cost after 1 month		
Cost after 2 months		
Cost after 3 months		

The results of your calculations should go on a table like this one.

Method 2: Payback Time

Buying the energy efficient light bulb means spending more money at the start, but it also means saving a little money every time you have the light on. A time will come when the savings are enough to pay back the extra cost of the energy efficient light. That time is called the **payback** time.

To find the payback for choosing a compact fluorescent bulb over an incandescent bulb, make a table showing the total cost for each kind of bulb month by month as time goes by. The payback time comes during the month when the total cost of using an incandescent light bulb catches up to the cost of using the energy efficient compact fluorescent bulb.

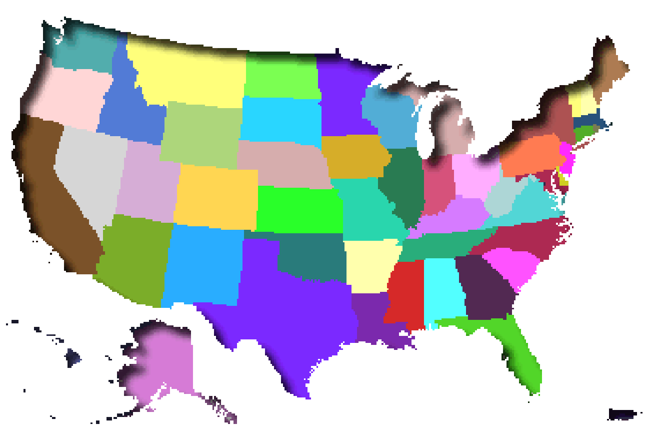
At the beginning of the first month the cost is simply the price of the light bulb. For each month after that add on a month's worth of energy costs. Assume the light is on for four hours a day. Use the wattage of the bulb and the energy cost (10¢ per kilowatt-hour) to calculate the monthly energy cost. Whenever the operating time of the bulb reaches the bulb's lifetime, add in the cost of a new light bulb. Make a graph of cost versus time. Plot the data for both light bulbs on the same graph. Where the two lines cross is the payback time.

Payback to the Energy Utility Company

Your electric utility company provides electricity to your home as long as someone pays the bills. The more energy people use, the more money the electric company makes—right? *Not necessarily!* What people really want and need are the services this energy provides. Light, heat, entertainment, and communication are a few of the services people expect to receive from their electricity.

With improved energy efficiency, energy utility companies can charge more per unit of energy while consumers pay less for their light, heat, and the rest. That is one reason why electric companies encourage energy savings. They have even offered money-saving deals on compact fluorescent lights.

There is another important way electric companies benefit from energy saving efforts. The demand for energy services increases as the population and the economy grows. There are two ways to meet the growing demand. The power company can spend hundreds of millions of dollars to build new power plants, or, by promoting energy conservation, it can provide more services with the energy from the power plants it already has.



Payback to the Country

According to a 1990 study by the Lawrence Berkeley National Laboratory, incandescent light bulbs in the United States use about 200 billion kilowatt-hours of energy each year. If half of the incandescent bulbs were replaced with compact fluorescent bulbs that gave the same amount of light, the savings would be about 75 billion kilowatt-hours, since most compact fluorescent lights are about four times as efficient as incandescent lights. At 10 cents per kilowatt-hour, this would save people in the United States eight billion dollars on energy bills!

Eighty billion kilowatt-hours of energy per year is the output of 16 large power plants, which could be retired and not replaced. Since the cost of a large power plant is approximately $1.5 billion, the overall savings to the power industry (and ultimately the American consumer) would be $24 billion.

Payback to the Planet

Over its lifetime, a *single* compact fluorescent light bulb saves in electrical energy the equivalent of 450 pounds of coal, or 40 gallons of gasoline. Ten compact fluorescent light bulbs operating continuously, 24 hours per day, save an amount of energy equivalent to the amount of gasoline needed to run a new car for a year. By saving that energy, not only would it save money for consumers, it would also:

- Reduce damage to the planet from mining and drilling.
- Reduce the amount of fuel transported, thus reducing the number of oil spills.
- Reduce air and water pollution.
- Reduce the amount of carbon dioxide injected into the atmosphere, thus reducing the risk of global warming.

Conclusion

Have you decided which light bulb to buy?

It's not just light bulbs. There are other ways to reduce the electricity bill in your home or school or community. Just as there are paybacks for saving electricity, there are paybacks for saving every other form of energy. The next chapter deals with a form of energy that is vital for human survival and comfort. It is also a form of energy involved in almost every energy transformation—heat.

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/9eu.html. We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

8. Energy for Heating and Cooling

Controlling the Flow of Heat

Keeping comfortable, or simply staying alive, requires a temperature that's not too hot and not too cold. As warm-blooded creatures, we have a built-in system for heat control. As intelligent humans, we augment our built-in systems with technologies—clothing, housing, and fire—that enable us to live in places where we could not otherwise survive. We have also learned to use heat in new ways—to make ceramics, to refine metals, to power automobiles and factories, and to fire rockets into space.

To conserve energy, we need to be able to control the flow of heat.

The science of heat energy has its own name—*thermodynamics*. To keep the heat we use in the places we want it, and out of the places we do *not* want it, we must understand the three processes of heat flow: conduction, convection, and radiation.

Heat Flow by Conduction

Your most vivid experiences of heat moving has probably been when you directly touch something. Climb into a car that has been sitting in the hot sun. The upholstery is toasty hot from hours of heating by the greenhouse effect. Ouch! How about the way your mouth feels after you bite off a big chunk of popsicle? In both cases your sensations are an immediate result of heat moving by conduction.

***Conduction* is movement of heat that occurs when two objects are in direct contact with each other.**

One principle of thermodynamics is that heat flow by conduction goes from the hotter object to the cooler one. When you bite a popsicle, you are sensing the flow of heat from the inside of your mouth into the chunk of popsicle. When you sit on a hot car seat, your skin is sensing the flow of heat from the car seat into your body.

Put your hand on a page of this book, then the floor, a window, a rug, something metal, and something plastic. Do they all feel the same temperature? They may *be* the same temperature, even if they do not *feel* the same temperature. How can this be? The reason is in how well they conduct heat. Metal conducts heat very well so when you touch it at room temperature, heat flows quickly out of your body—you feel cold. Something made of wood, also at room temperature, feels warmer because heat flows very slowly out of your body into the wood, which is a poor conductor of heat.

Question 8.1
What are other examples of heat conduction?

Investigation

How Does the Thermos™ Bottle Know?

Three science teachers were relaxing after a hard day at school. Their talk turned to the great technological achievements of the modern world. One said, "There is nothing that can beat computers. Computers can do more and more, and they are getting smaller and smaller, and cheaper and cheaper. It's amazing!"

"What about lasers?" the second teacher said. "They are everywhere! I'll bet in a few years lasers will be used in ways we cannot even imagine now. Lasers certainly rival computers!"

"And then there are Thermos bottles," added the third teacher.

"Thermos bottles?" said the others. "What is so special about Thermos bottles?"

"Well," explained teacher number three, "if you put something hot in one it stays hot. If you put something cold in one it stays cold. How does the Thermos bottle know what it's supposed to do?"

As you read this chapter, and you discover other ideas of how a Thermos™ bottle works, feel free to change your explanation.

QUESTION 8.2

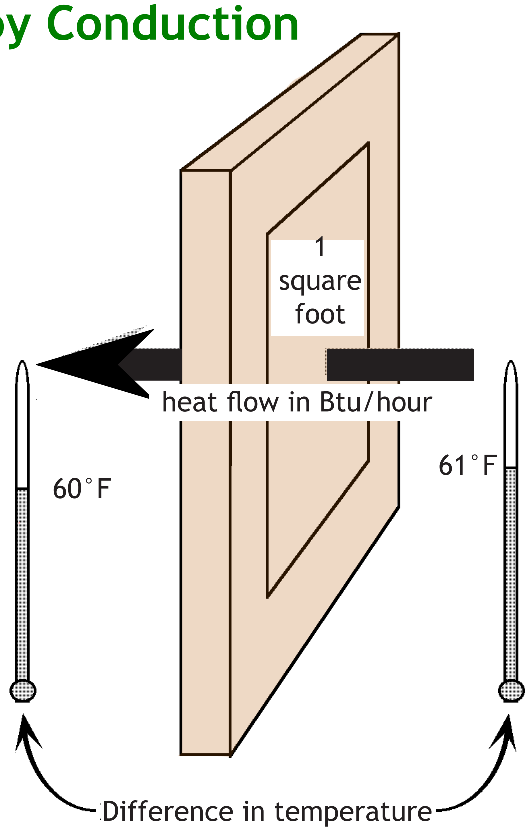
How does the Thermos™ bottle know? Write down your ideas about how you think a Thermos™ bottle keeps hot things from cooling off and cold things from warming up.

Insulation—Preventing Heat Loss by Conduction

In the walls or ceiling of a house or apartment, insulation helps minimize house heating costs and energy waste by keeping heat from escaping. Insulation conducts heat poorly. The measure of a material's ability to resist the flow of heat is called its *R-value*. A standard single pane window has an R-value much less than one. A lot of heat escapes through a single pane window. In cold climates, it is wise for home owners to insulate their ceilings to at least R-30.

R-value is the difference in temperature on either side of a material, divided by the rate of heat flow in Btus per hour per square foot.

For example, a window with an area of one square foot, that is one degree Fahrenheit warmer on one side, lets heat flow through at a rate of 1 Btu per hour. It would be R-2 if it allows only one-half a Btu to flow through per hour; and R-30 if just one thirtieth of a Btu flows through per hour.



R-VALUES for Thermal Insulators and Other Materials		
Material	Thickness	R-value
Felted Cattle Hair	1/4″	1
Fiberglass	4″	15
Sheep's Wool	1″	4
Gypsum Wall Board	1″	0.3
Wood	1″	1-3
Glass	1/8″	0.02
Building Brick	4″	1
Concrete	8″	1

There is a wide range of R-values in common building materials. A four-inch thick brick wall is not a good insulator. By making it twice as thick you could double its ability to reduce heat flow, but you could get the same insulation by adding a layer of felted cattle hair. It would be less expensive and it would take up less space.

A home builder in a cold climate is always interested in the best insulation. Goose down—tiny feathers used in expensive pillows and sleeping bags—has a very high R-value. But insulating a house with goose down would not be very practical. For a building, the choice of insulation depends not only on R-value but also on cost, strength, durability, ease of handling, and fire safety. Materials used for insulation include fiberglass, foam boards, sheet rock, double pane windows, and wood. Some insulation is even made from cattle hair or sugar cane fiber.

Investigation

Compute the R-Value of a Material

a) Find the temperature difference **∆T** on the two sides of the material

b) Multiply it by the area **A** of the material

c) Divide it by the rate of heat flow **∆H** through the material.

R-value = ∆T x A / ∆H

Question 8.3

What is the R-value of a 2-square-foot window that allows 20 btu of heat to flow through it per hour?

The indoor temperature is 65°F and the outside temperature is 55°F.

Celsius (°C) to Fahrenheit (°F)

Use this formula to convert °C to °F:

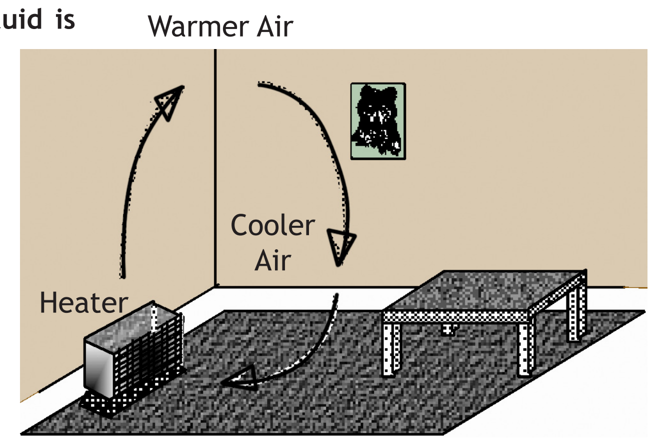
°F = (°C x 9/5) = 32

We use non-metric temperature (°F) in our calculations because most American energy-related industries have not converted to the metric system. To use °C would add an extra step of complexity to figure out the R-value of insulation, which use btus and °F.

Heat Flow by Convection

Air conducts heat very poorly. Yet, when a house is built in a cold climate the air spaces in the walls and the ceilings are often filled with insulating materials. Why isn't the air alone enough to do the job? The answer is that air does not sit still, and when air flows, its energy flows with it.

The flow of heat by way of a moving fluid is called *convection*.



As air warms up, it expands and becomes less dense than the surrounding cool air. The warm (less dense) air is pushed upwards by the cold (denser) air. That principle is what makes a hot air balloon float upwards. A heater in a room warms the air just above it. The air rises to the ceiling, cools and drops to the floor, where it is heated again. That is a *convection current*.

Convection currents do not always distribute heat where it is needed. A layer of hot air near the ceiling does not give much comfort to the people below. A ceiling fan can send the warm air back down. Although a fan uses electricity, it may save on the overall cost of energy bills.

A fire in the fireplace might be a good way to warm the place up, right? Wrong! Convection strikes again, in a big way. Convection does not just carry smoke up the chimney; it carries warm air up the chimney too! An airtight wood stove works better by limiting convection.

Convection is one reason it is especially important to insulate a roof well. If it is 60˚F inside and 50˚F outside (a 10˚F difference), it is possible that convection has carried a layer of warm air to the roof raising the inside temperature to 80˚F at the roof (a 30˚F difference). If the R-value were the same in the walls and the ceiling, the heat loss per square foot through ceiling would be three times the heat loss through the wall

Radiant Energy—Heat Flow at the Speed of Light

What material would stop heat flow best of all? The best heat barrier is nothing—a vacuum—empty space. But even a vacuum cannot stop heat completely. If it could, we would never be able to feel the warmth of the Sun across the emptiness of space. Some heat energy passes between objects that are not touching, even if there is empty space between them. That process of heat flow is called *radiation*; and the kind of energy that travels by radiation is called *radiant energy* (or electromagnetic energy).

Heat is always being converted into radiant energy. You can see (and feel) this transformation every time you use a incandescent light bulb. Inside the light bulb is a tungsten metal filament—the long narrow wire—which heats up to more than 1832°F as electricity flows through it. Some of the heat changes into brilliant white light—a visible form of radiant energy.

Look around you now. There is probably nothing near you that is as hot as the inside of a light bulb, but everything around you has some heat in it. Everything around you is giving off some of that heat as radiant energy. Only the *very* hot things such as light bulbs give off light you can see. Cooler objects give off *infrared* energy that you cannot see.

Objects lose heat when they give off radiation, and they heat up when they absorb radiation.

Which gets hotter in the sunshine; a white concrete sidewalk, or a black asphalt road?

You certainly know the answer if you have ever stepped off the sidewalk to cross the street in bare feet on a very sunny afternoon. Dark surfaces absorb visible light better than light surfaces. The absorbed energy becomes heat. Most objects, no matter how dark or light they look, absorb infrared radiation, so heat lamps are made to emit infrared energy.

Radiant Energy for Heating—Free Deliveries Daily

Each year radiant energy from the Sun brings to Earth 15,000 times more energy than the world's estimated supply of fossil fuels. Solar energy can be harvested in homes by arranging windows to maximize the use of solar heat. Most people who employ solar heating systems in their homes find it necessary to use conventional heating systems as a backup. Used this way, solar energy may be considered to be an energy conservation strategy—the use of solar energy reduces the need to use fossil fuels for heat.

In one solar heating design, large windows are positioned facing south. Sunlight enters the house and is absorbed by heat storage materials such as a dark rock slab floor or large dark-colored containers of water. A large object that stores heat is called a *thermal mass*. The thermal mass absorbs heat during the day and radiates heat at night to keep the home at a comfortable temperature.

Clear windows allow a *greenhouse effect* to heat the house. Here is how it works: Sunlight is about half visible light energy and half infrared energy. About 98% of visible light and 50% of infrared energy pass through windows; so about 73% of the total amount of energy that strikes a window makes it into the house. Once inside the house, nearly all the light is absorbed by objects in the house and is reradiated as *infrared* energy. Only 50% of this infrared radiation can pass back out through the windows, and the rest is trapped inside. Heat keeps accumulating until the temperature inside the house is high enough that the total energy entering the house equals the total energy escaping from it.

Buildings that use the Sun for some or all of their energy without fans or pumps are called *passive solar* buildings. The house pictured on this page is a passive solar house. The benefit of passive solar design is that it adds no energy cost to a building. There is really no reason, besides architectural taste, not to incorporate passive solar designs into building plans.

The Electromagnetic Spectrum

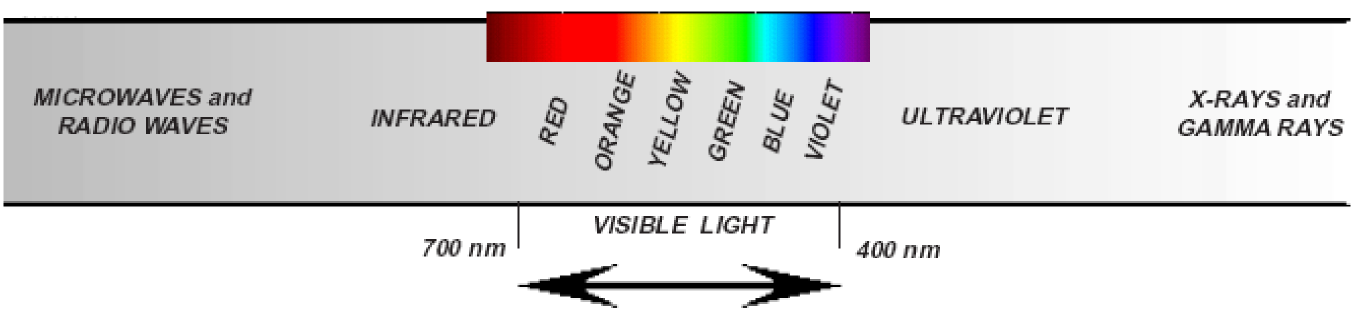
Traveling waves of electric and magnetic fields are known as ***electromagnetic radiation.*** Like water waves which can be long rolling swells or short choppy waves, electromagnetic waves can be long or short. The length of the wave—called the ***wavelength***—determines how it behaves.

Visible light has wavelengths between 400 and 700 nanometers. (A ***nanometer*** is one billionth of a meter.) The exact wavelength determines the color of the light.

Visible light is partly absorbed and partly reflected by most materials. We see things by the light they reflect. Objects are warmed by the light they absorb. ***Infrared radiation,*** which has longer wavelengths than visible light, is easily absorbed by most materials and will heat them up. ***Ultraviolet*** light (UV) has shorter wavelengths than visible light. UV light can heat an object, but it can also cause chemical changes and damage to materials including skin.

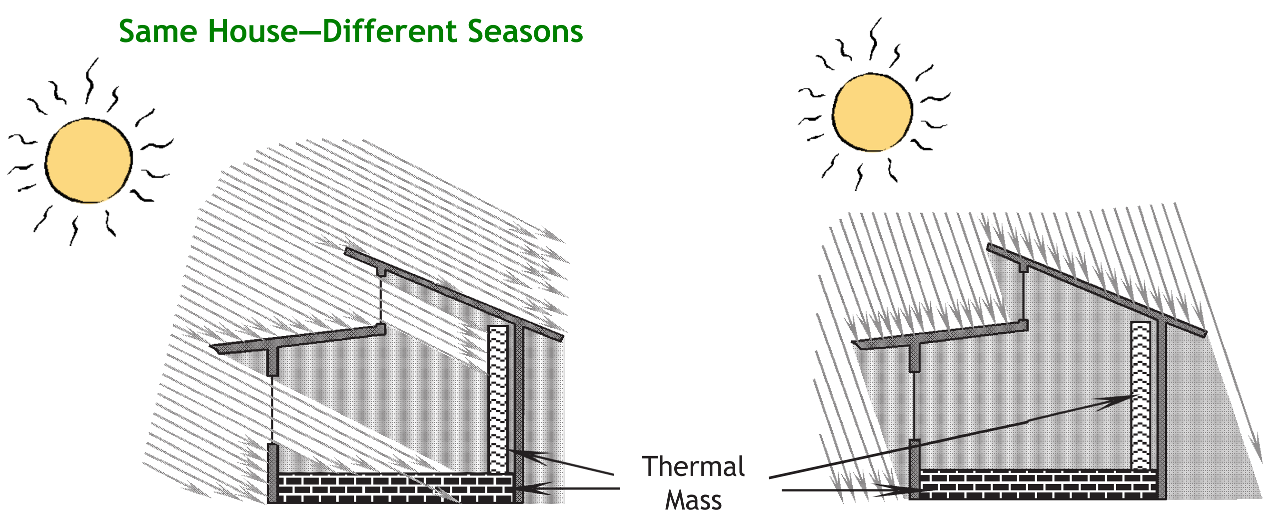
Near one end of the electromagnetic spectrum is radiation with the longest wavelengths (microwaves and radio waves), while at the other end is radiation with the shortest wavelengths (X-rays and gamma rays).

The Sun radiates the entire spectrum. Most of the energy in sunlight that reaches Earth is in the form of visible light and infrared, but there is a lot of ultraviolet radiation as well. The warm feeling you get from sunshine on a cool day is from infrared radiation. Ultraviolet radiation from the Sun causes burns and skin cancer. Fortunately most of the ultraviolet radiation never reaches the surface because it is blocked by ozone gas in the upper atmosphere.



In the diagram above, there is no connection between the wavelenth span depicted for each type of wave or ray and the actual wavelengths. Consider that the longest radio waves can meters long, while visible light waves are less than a millionth of a meter.

Same House—Different Seasons



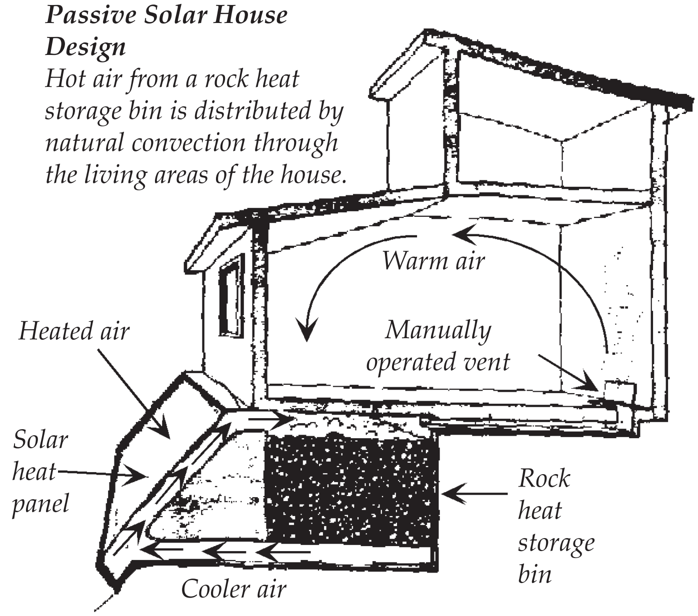
In WINTER the sun's rays shine in and are absorbed by a thermal mass

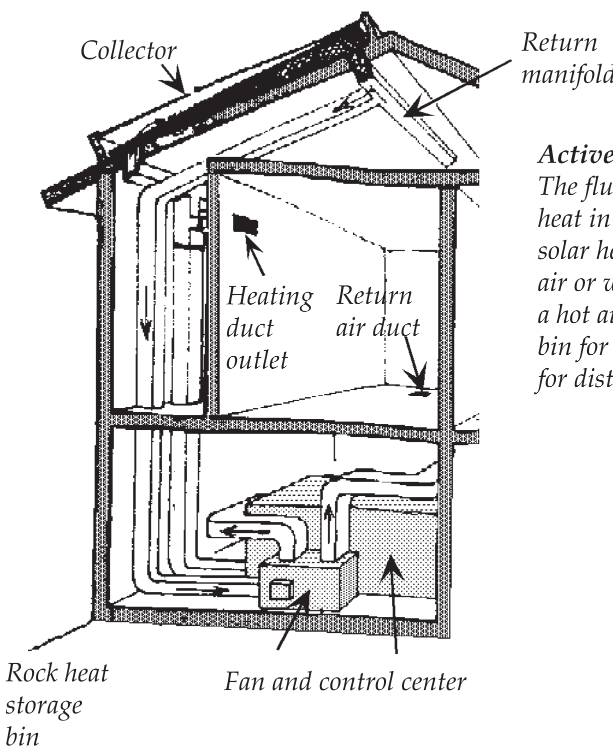
In SUMMER the Sun's rays cannot shine into the house

Passive and Active Solar House Heating

If your home is heated by burning natural gas, the heat is probably spread around to the living spaces in the house by blowing hot air through ducts or pumping hot water to radiators. In solar heated buildings, heat can come into the living spaces directly through the windows, or accumulated in solar collectors using either hot air or hot water for collecting heat. The heat is stored in rock bins (with hot air solar collectors) or water tanks (with solar water heating panels). In *passive* solar houses, the collected heat is distributed through the house by convection. If fans or pumps are used to circulate the heat through the living spaces, then the building design is *active solar*.

Passive Solar House Design
Hot air from a rock heat storage bin is distributed by natural convection through the living areas of the house.

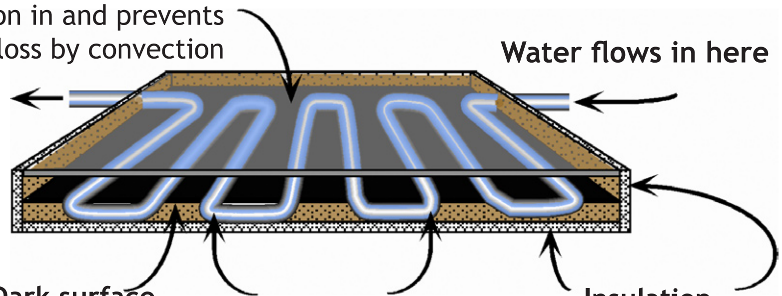




Active Solar House Design
The fluid that distributes heat in buildings with active solar heating can be either air or water. Pictured here is a hot air system with a rock bin for heat storage and fans for distribution of heat.

Solar Hot Water

It's easy to heat water with sunlight. Solar heated water can be stored for home heating, or used for bathing, laundry, and dishes. Here is a diagram showing a typical solar water heating panel that can be installed on the roof of a house.



Investigation

Refrigerators

Josh and Bert met after school and were looking for a snack in the kitchen at Bert's house. Josh said, "This kitchen is hot! Can't you open a window or something?"

"What good would that do?" Bert said. "It's even hotter outside. Besides, we shouldn't open the window because the air conditioning is on."

Josh said, "Let's open the refrigerator door. That should cool things down." Bert pulled open the refrigerator and they both stood in front of it and enjoyed the feeling of the cool air.

Bert said, "I guess no food will spoil if we leave the refrigerator open for a few minutes. Listen to it hum!"

"You know," said Josh, "our science book says that energy is never used up. It just changes from one kind of energy to another. So where does the energy go that runs the refrigerator?"

"The refrigerator takes electrical energy and uses it to make things cold. So I guess it turns electrical energy into cold energy," Bert said.

"No, that can't be right," Josh said. "I know that heat is a kind of energy, but I've never heard of *cold* energy."

In charged Bert's mother. "Close that refrigerator!" she said. "It's too hot in here already!"

Does Bart's mother's request make sense?

Investigation *(continued)*

Josh knew that energy is never used up. Bert was aware that heat is a form of energy. They have an inkling of the *first law of thermodynamics*: (also called the *law of conservation of energy*) that energy can neither be created nor destroyed, but can change from one form to another. The *second law of thermodynamics*, that everything tends to go from a state of order to disorder, is harder to grasp. But one of its consequences is that heat flows from hotter places to cooler places. A refrigerator, however, seems to do just the opposite. It makes itself cold on the inside by moving heat from the cooler inside to the warmer outside.

The second law of thermodynamics *does* allow for heat to move from a cooler place to a hotter place, but it *always* requires work—the input of more energy. The energy that does the work to move the heat also *adds to the total amount of heat in the system*.

Bert's mother understood that by forcing the refrigerator to keep running, the boys were producing even more heat in the kitchen.

Question 8.4

How could keeping the refrigerator door open make it hotter in the kitchen?

Question 8.5

Why do you think Bert was confused about what happened to the energy in the refrigerator?

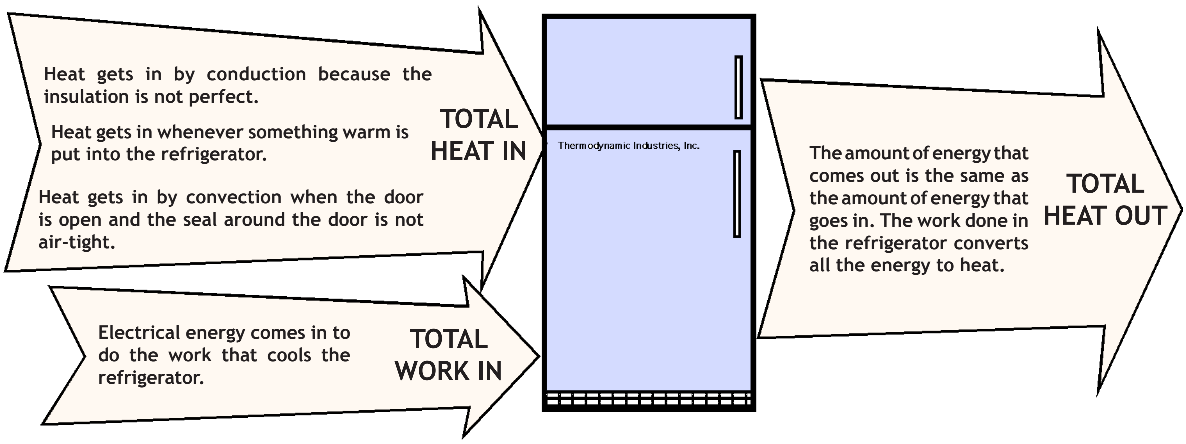
Is there such a thing as "cold energy"?

Question 8.6

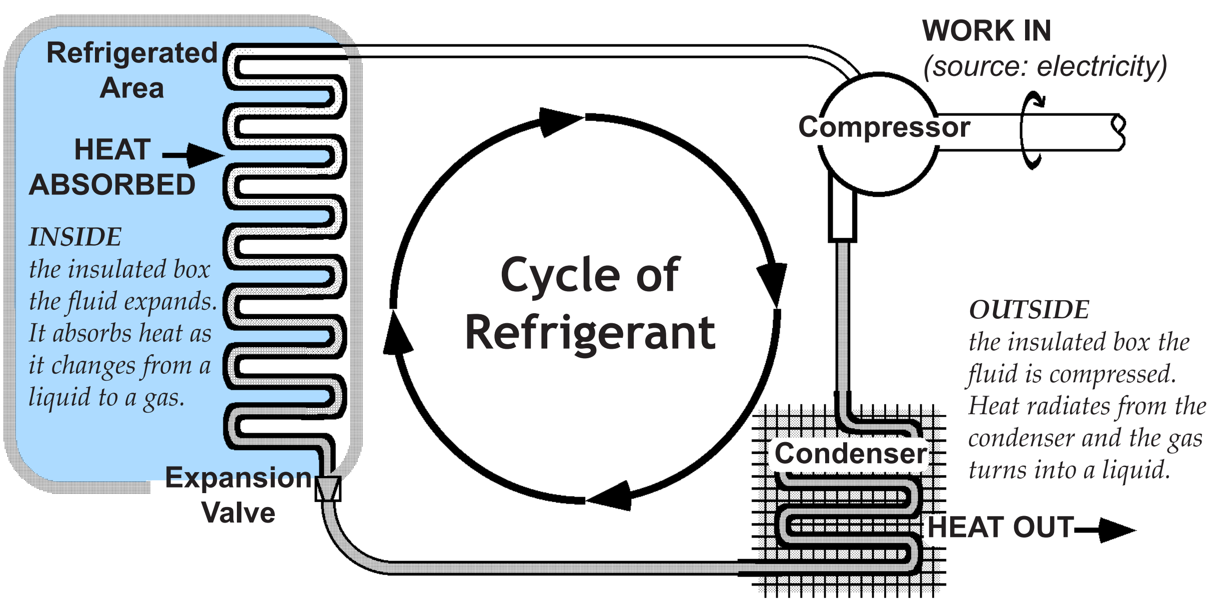
Josh did not seem to be confused. Do you think he had a better understanding of what a refrigerator does?

How a Refrigerator Works

A refrigerator is a double-walled insulated box with a system of pipes between the walls that have a "working fluid" flowing through them. When the fluid runs through the pipes *inside* the insulated box, it changes from a liquid to a gas as it absorbs heat from inside the box. The fluid is then compressed and pumped outside the insulated box to *condenser coils* where it changes back to a liquid by releasing heat it absorbed from inside the box. The condenser radiates heat to the surrounding air outside the refrigerator.



Energy Flow in a Refrigerator



Working Fluid Circulates in a Closed Loop in a Refrigerator
Compare this diagram to the diagram of the cycle of water in a power plant in chapter 4. The power plant cycle uses the flow of heat to do work. The cycle of a refrigerant uses work to create a flow of heat.

Building a Better Refrigerator

In 1993, a consortium of 24 utility companies sponsored a contest with a $30 million prize for the best new refrigerator on the market. Entrants had to build a product 50% more energy efficient than current refrigerators. They also had to have a plan to market their product.

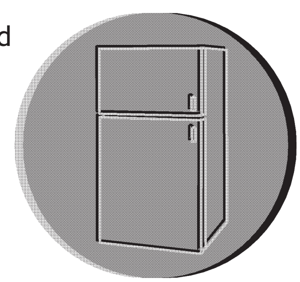
Another requirement for the winning refrigerator was that it could use no chlorofluorocarbons—CFCs. For decades the working fluid in most refrigerators has been freon, a CFC fluid. Freon released from air conditioners and refrigerators is a major contributor to the destruction of ozone in the upper atmosphere that protects us from the lethal ultraviolet rays of the Sun. It has become urgent that freon in old refrigerators be recycled rather than released to the air and that alternatives to freon be used as working refrigerator fluids. Whirlpool won that contest but you can find energy efficient refrigerators among all the major brands.

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/9eu.html. We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

Investigation

Exploring a Refrigerator

Let's explore some parts of the refrigerator that keep it cold and some parts that move heat energy from the interior to the exterior of the refrigerator.



Materials

- Refrigerator or freezer.
- Refrigerator owner's manual if it is available.

Examine the walls and door of the refrigerator. Look for features that help keep heat out.

Look on the outside of your refrigerator for the condenser coils. The owner's manual may help you to find them. They are probably on the back side or the bottom of the refrigerator, or both. Look for features that help send heat from the coils into the air away from the refrigerator.

- *Did you find the condenser coil?*
- *Did it feel warm?*
- *What color is it?*
- *How does its color help it to function properly?*
- *Why do you think that this part of the refrigerator has so many thin pieces of metal welded to it?*

If you check your refrigerator's manual it will almost certainly give instructions on cleaning this part of the refrigerator.

Question 8.7 How might a dusty condenser coil keep heat from getting away from your refrigerator.

Question 8.8

Does the article on this page have any tips you could follow today?

Why does an electric company care if your refrigerator is energy efficient?

Source: Pacific Gas and Electric Company newsletter, June 1991

Slash Your Refrigeration Costs

It's possible to cut your refrigeration costs by up to half. How? By replacing your old refrigerator with an efficient new model and by keeping your refrigerator's coils clean.

And here's the best part: PG&E will pay you to save. That's right — you can receive a PG&E rebate of up to $150 by buying an efficient refrigerator from a participating store between June 1 and September 30. Ask an appliance salesperson which models qualify.

Get $50, $75 or $150 back on an energy-efficient refrigerator bought from a particpating retailer June 1 through September 30.

A new refrigerator uses a lot less electricity than one just eight to ten years old. In fact, a super-efficient model can operate for half the cost of an older model. The most efficient can save you up to $850 over its useful life, compared to a new model that just meets federal efficiency standards.

There's more to buying a refrigerator than choosing the color, size and features you want. Also consider the following:

- Choose a unit that's the right size for you and your family. Too large a unit will use more energy than necessary.
- Read the refrigerator's EnergyGuide label to find out its estimated yearly energy cost compared to similar models.

Clean Coils Cut Costs

Keeping refrigerator condenser coils clean makes good economic sense. A unit with dirty coils can cost 25 percent more to run than one with lint-free coils. Dirty coils may also reduce the life of the refrigerator's compressor.

Clean coils at least once a year — every three or four months is better, especially if you have a pet that sheds a lot of fur. Here's how:

- Turn off refrigerator, then unplug it if possible.
- To clean bottom coils, carefully remove the toe grill covering them — just vacuuming the grill won't help. You'll need a long-handled narrow brush or refrigerator brush to reach all the coils under the unit. Pull the lint out with the brush and vacuum the lint off the brush as you go.
- If your coils are on the back of your refrigerator, you may need to move the appliance out a little. Put something under the front legs to protect the floor, then rock the refrigerator back and forth to move it out. Make sure you don't dislodge any water pipes or drip pans, if present.
- Plug in the refrigerator and turn it back on.

More Tips to Help You Save

- Make sure the refrigerator's temperature isn't too low or too high. A temperature of 38 to 40 degrees is recommended; use a refrigerator or room thermometer. The freezer should be about zero to five degrees.
- If possible, turn off the heater that keeps condensation from forming on the panel between the freezer and the refrigerator door. In most of California, the humidity is so low that condensation isn't a problem. The switch is usually found inside the refrigerator compartment. Check your owner's manual for the proper setting. This step will save about $.25 to $1.50 a month.
- If you have a second refrigerator or freezer used only occasionally, unplug it or give it to charity. You could cut your annual electric bill by as much as $175.
- Avoid clutter around the refrigerator to let the unit ventilate itself properly.

9. Energy for Transportation

There's an old song from the early days of automobiling. "Come away with me Lucille. In my merry Oldsmobile." You don't know that one? How about this? "Oh Lord, won't you buy me a Mercedes Benz?" No? Well you probably know *some* car song. After all, people in the United States drive trillions of miles in cars every year. It comes to about 12,000 miles a year for each person. And look out, the number of cars and the distance traveled grows greater each year.

About a quarter of the carbon dioxide from burning fossil fuels in the United States comes out the tail pipes of cars. One tankful of gasoline produces hundreds of pounds of carbon dioxide, which increases our planet's susceptibility to global warming. This is not to mention the carbon monoxide, nitrous oxide, and hydrocarbons that pollute the air.

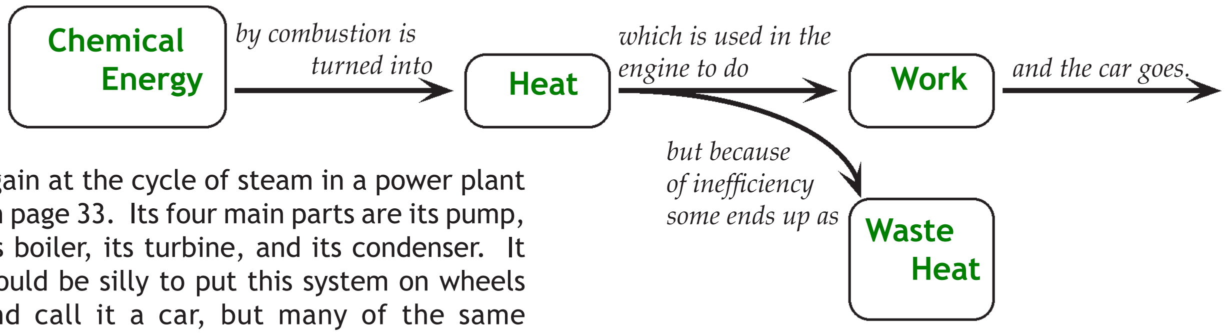
Photo courtesy of pdphotos.org
The Daily Commute
In nearly every large city in the world people are treated to a vision like the one in this picture. If consumers demanded that new cars be 50% more fuel efficient, city air would be much healthier to breathe. If cities maintained efficient mass transit systems and if those who lived near public transportation took the bus or subway instead of driving, the morning commute would be a breeze!

The good news is, except for carbon dioxide, newer cars are producing far fewer pollutants per gallon of gas. New cars go farther on a gallon of gasoline too. The bad news is more people are buying trucks and vans so the overall gas mileage in the United States is going down. People are driving their vehicles more miles each year, and there are more vehicles on the road—about half a billion cars and trucks worldwide. With the approximate 5% growth in the number of new motor vehicles each year, by 2030 there will be a billion cars and trucks operating in the world.

The Car—What's Really Going On?

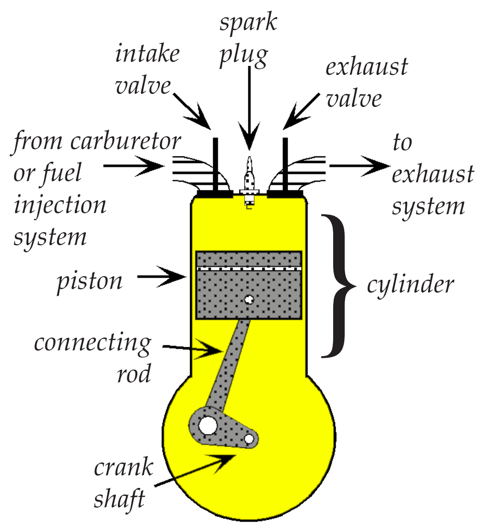
In our study of global systems science, we think of our planet in terms of a collection of interconnected subsystems: life in ecosystems, weather and climate systems, systems of ocean currents, and the geological system of Earth's crust. A car, like the Earth, is a collection of interconnected subsystems; the electrical system, the fuel system, the exhaust system, the braking system. All the systems are important for the safety and performance of the car. The details can critically affect the environmental impact of a car. Before we go into the details let's look at the main sequence of energy transformations that make a car run.

It is exactly the same sequence of energy transformations that occurs in fossil fuel power plants, but in the plants, the work was used to turn a generator instead of push a car along. Look



again at the cycle of steam in a power plant on page 33. Its four main parts are its pump, its boiler, its turbine, and its condenser. It would be silly to put this system on wheels and call it a car, but many of the same principles that make it work apply to a car.

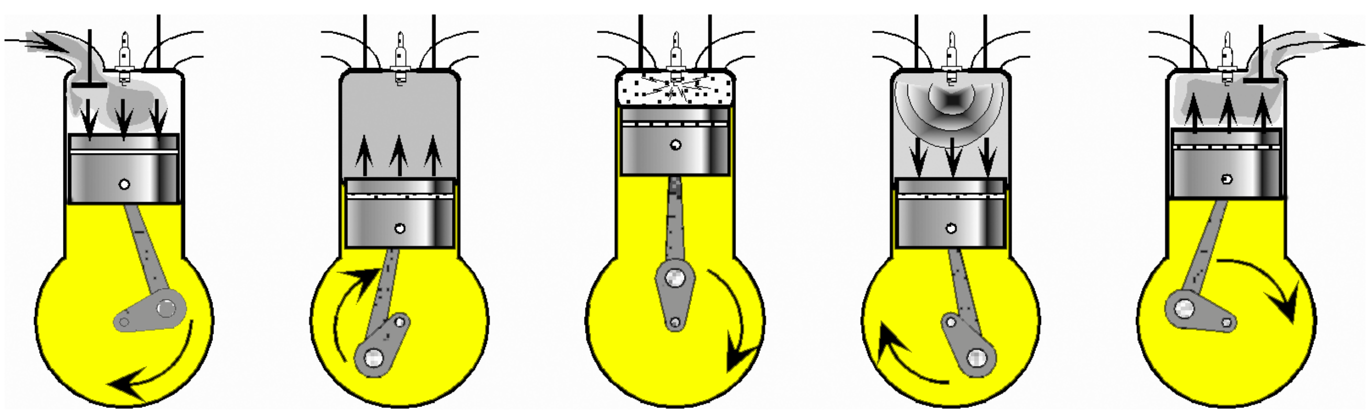
Instead of using steam to push the blades of a turbine, a gasoline engine uses hot gases to push a *piston*. The hot gases are the result of the combustion of gasoline. The gasoline burns in the *cylinder*, which is the same chamber that holds the piston. Since combustion happens inside the cylinder, and not in an external boiler, this type of engine is called an *internal combustion engine*.



This diagram shows the sequence of events in one of the cylinders of a typical internal combustion engine. A cylinder performs different functions during different parts of the engine's cycle. Compare it to the diagram of the power plant on page 29.

Four-Stroke Cycle

An automobile engine usually has four to 12 cylinders. As the engine turns, the pistons in each of the cylinders take turns at doing the work of making the car go.



1ST STROKE: INTAKE *Piston draws a mixture of air and gasoline vapor in through the intake valve.*

2ND STROKE: COMPRESSION *With both valves closed, the piston compresses the mixture.*

IGNITION *An electric spark from the spark plug sets off a rapid combustion of the gas vapor.*

3RD STROKE: POWER *Hot gases from the combusted gasoline push on the piston.*

4TH STROKE: EXHAUST *Piston forces the combustion products out the open exhaust valve.*

The Engine Does More Than Make the Wheels Go Round

"Hey, driver! The Sun's been up for an hour. Switch off the headlights!"

"Why jump on me about it? There's no harm in having the lights on. Is there?

"It wastes energy."

"C'mon! The engine's running whether the headlights are on or not."

"Where do you think the energy to run those lights comes from?"

The power to run the headlights comes from the battery. The battery is charged by the generator. The generator is turned by the engine. The disagreement concerns whether the engine must use more gasoline per mile when the lights are on than when they are off.

In this case, the passenger is right. The generator must produce electricity to power the spark plugs, and also keep the battery charged. When the lights are on, there is a greater load on the generator, so there is a greater load on the engine. As the engine works harder it burns more gasoline per mile. This is true when the headlights are on, when the air conditioning is on, or when any other electric device is on. The heater in a car uses waste heat from the engine. The only load that the heater puts on the electrical system is from the fans that blow the warm air into the car.

Getting the Most from a Car

There are many things automotive engineers can do to design cars that use fuel more efficiently and pollute less. They can make cars lighter. They can make them run at a higher temperature and find better ways to cool the exhaust. They can increase the amount of chemical energy in gasoline, and remove the most toxic gases from the exhaust. But the one thing they cannot control is how you drive your car.

There are three very simple reasons for every driver to drive in an energy efficient manner: (a) to reduce air pollutants that affect us all; (b) to save money in fuel, and (c) reduce car maintenance costs. There are many things a driver can do to increase fuel efficiency, conserve energy, and save money.

Investigation

Automobile Energy Transformations

As you drive, you are manipulating at least four types of energy: electrical, chemical, mechanical (motion), and thermal (heat). Energy from the driver turns the key and presses the pedals, buttons, and switches, but that energy does not make the car go. Here is a list of events that occur in the car. Each one is an energy transformation.

When You Turn the Key

- The battery makes electricity for the electric starter motor.
- Electric starter motor turns the engine crank.

When You Step on the Accelerator

- The fuel pump feeds gasoline to the carburetor.
- The carburetor mixes gas with air to create a spray that goes into the cylinder.
- The battery sends electricity to the spark plugs.
- The spark plug ignites the mixture of gasoline and air in the cylinder.
- The gasoline-air mixture explodes.
- The expanding hot gases from the combustion push the piston down.
- The piston turns the crank shaft.
- The clutch connects the crank shaft to the transmission.
- The transmission turns the drive shaft.
- The drive shaft spins gears that turn the wheels.
- Wheels push on the road, propelling the car forward.
- Air resistance pushes back against the car.

Meanwhile

- The engine turns the generator (or alternator).
- The generator produces electricity.
- The electricity charges the battery.
- The electricity runs the lights, fuel pump, radio, and other devices.

When You Step on the Brake

- Brake shoes rub the brake drum in the wheel.
- Friction between the brake drum and the wheel stops the car.

Question 9.1
Which one of the events is the transformation from chemical energy to heat energy? [It's not the first one on the list, but it is the one that really makes the whole system go.]

Follow the energy from transformation to transformation, starting with "The gasoline-air mixture explodes," and answer the following questions.

Question 9.2 Where does the energy go from there?

Question 9.3 At which points does the energy branch off in more than one direction?

Question 9.4 Where does all the energy eventually go?

Fuel Efficiency Enemy #1: Friction

How fast you go dramatically affects air friction.

Air resistance is proportional to the 4^{th} power of your car's speed. That means if you double your speed, your air friction doesn't just increase by a factor of two, it increases by a factor of 16. ($2^4 = 2 \times 2 \times 2 \times 2 = 16$). This is especially noticeable at freeway speeds where for each 10 miles per hour faster you go there is a substantial increase in fuel needed.

During the 1973 energy crisis, President Gerald Ford instituted the 55 mile per hour speed limit. Its intent was to save fuel so the United States would not depend so much on foreign oil. Over the years the 55 miles-an-hour speed limit resulted in substantial savings in the cost of driving, reduced air pollution, and saved thousands of lives in speeding fatalities each year. In many states, however, lawmakers raised the speed limit, deciding that extra speed is worth the extra costs, especially since many motorists ignored the lower speed limit anyhow.

Air pressure in your tires affect friction with the pavement.

Driving with low air pressure in your tires can dramatically reduce fuel efficiency. A soft tire flexes under the weight of the car so there is more tire on the road and thus more friction. As the wheel turns, the rubber bends back and forth rapidly. This heats the rubber and you use gasoline just to make the tires hot!

A well-tuned car burns gas more efficiently and saves fuel.

A well-lubricated car has less internal friction.

Replacing the oil and oil filter regularly increases fuel efficiency by minimizing internal friction in the engine. It will also prevent your engine from wearing out as quickly.

Fuel Efficiency Enemy #2: Stop and Go Traffic.

Continual stopping and going is one of the most important factors in how much fuel you use. It is much more important than air friction, since your speed is not very high. Every time a vehicle comes to a stop, all its energy of motion is converted into heating the brakes.

Acceleration matters

Every engine has a peak efficiency at some particular engine speed.

Navigate the traffic lights

Many city streets have traffic lights that are timed precisely so drivers who travel slightly under the speed limit will never encounter a red light.

Stop at the stop signs

If you are driving on a street with a lot of stop signs, there is an optimal level of acceleration, cruising, and braking that will make the most efficient use of fuel.

Is your car overloaded?

What do you keep in the trunk or the rear storage compartment? If you use your car or truck to store heavy items you will pay for it by using extra gas going uphill, and by putting extra wear on your brakes going downhill.

What kind of car will you buy?

The heavier the car, the more gas it guzzles. The more powerful the engine, the more gas it guzzles. Older cars tend to guzzle more gas.

Some people buy large, heavier cars because of the protection they give in an accident. Some small car drivers say their cars are more maneuverable than heavier cars, and so their small cars can more easily avoid accidents. Most fatalities in car accidents are in midsize cars rather than small or large cars. Improved seat belts, air bags, anti-lock brakes, and other technology make new cars of all sizes safer than older cars. If you are looking for safety, you are in luck. The driving habits that save fuel are also the driving habits that help avoid accidents.

Photo courtesy of www.wikipedia.org

Some drivers get great pleasure from the feel of a very powerful machine in their control. The more powerful, the better the feel. Some of those drivers may not have the slightest desire to save on fuel. However, when fossil fuel gets scarcer, its price will go up. Car buyers may become more willing to sacrifice engine power by the time the cost of gasoline gets above $4.00 per gallon as it already is in much of the world.

Question 9.5

Which of the following practices do you think saves the most fuel? Why?

a. Stomping on the gas pedal for maximum quick start.

b. Accelerate moderately quickly.

c. Accelerate as slowly as possible.

Question 9.6

Which of the following practices do you think saves the most fuel? Why?

a. Race up to each red light; come to a dead stop, and then accelerate to the next red light.

b. Find the right speed (at or below the speed limit) to "time the lights" so that you rarely need to brake at all.

Question 9.7

Which of the following practices do you think saves the most fuel? Why?

a. Accelerate almost all the way up to a stop sign and then brake very hard in the last few yards.

b. Accelerate moderately, cruise at a constant speed, and leave plenty of distance to make a safe, gradual stop.

Question 9.8

How does a large car affect the safety of other cars and people involved in the accident?

Question 9.9

What would you look for in a car?

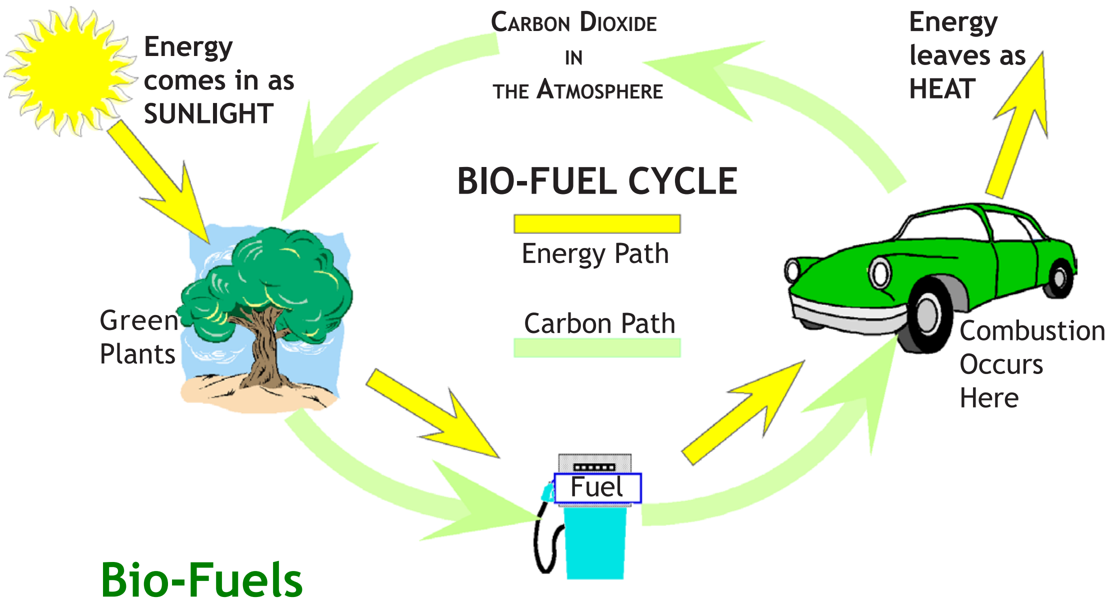
Alternative Fuels

It is very unlikely that we will be able to totally eliminate fuel-burning vehicles in the near future. However, a far-reaching solution is being tested in states with serious smog problems, such as California, is to encourage development of automobiles that can burn alternatives to gasoline and diesel fuel.

Natural Gas

One strategy is to make cars that run on lightweight fuels such as propane or natural gas (methane). Unlike gasoline, which is liquid at normal atmospheric pressure, propane and methane are gases. Therefore, a car with a tank full of natural gas won't go very far unless the gas is pressurized to turn it into a liquid. Even more fuel can be stored in a "thermos" tank that can store natural gas that has been cooled until it is a liquid.

The disadvantage of this alternative fuel is that it is still a fossil fuel. As with all fossil fuels, it releases carbon dioxide, contributing to global warming.



The Bio-Fuel Cycle
Compare this diagram with the diagram of the fossil fuel cycle on page 23. It seems only the title is different. There are important differences that the diagram does not show. The bio-fuel pump provides ethanol or methanol instead of gasoline. In the fossil fuel cycle the transition from energy-rich plant material to fuel involves natural geological processes that take millions of years. In the bio-fuel cycle the transition is done on a short time scale. When biofuels are renewed at the same rate as they are burned, they cause no build up of carbon dioxide in the atmosphere.

Bio-Fuels

It is possible to convert many types of organic materials into usable *bio-fuels* such as alcohol, methane, and hydrogen. Suitable organic materials include farm crops, aquaculture farm products, wood, and garbage. Fuels can be made by heating the organic materials or by treating them with microorganisms. Unlike fossil fuels which can be used up, bio-fuels are a part of a renewable energy cycle. Plants use sunlight and CO_2 from the air to produce energy and grow new tissue. Dead plants are converted to alcohol. When the alcohol is burned, CO_2 returns to the atmosphere. The bio-fuel cycle does not increase or decrease the amount of CO_2 in the atmosphere as long as new plant growth is established as a source for the fuel.

Alcohol synthesized from farm crops is now being marketed as a fuel to run automobiles using a mixture of gasoline and alcohol known as *gasohol*. Vehicles can even run on pure methanol, the simplest type of alcohol. In 1990, engineering students from the University of California, Davis, set a world record for fuel efficiency in an alcohol-powered vehicle. In four laps of a 1.75 mile track, their 2-horsepower vehicle, named "Shamu," consumed so little methanol that the fuel efficiency was 2,083 miles per gallon. However, in the same competition, a gasoline-powered vehicle achieved 3,313 miles per gallon. The difference is due to the fact that gasoline has more energy per unit volume than methanol. That test highlighted a disadvantage of bio-fuels—as they are less efficient than gasoline—you need more bio-fuel than gasoline to go the same distance.

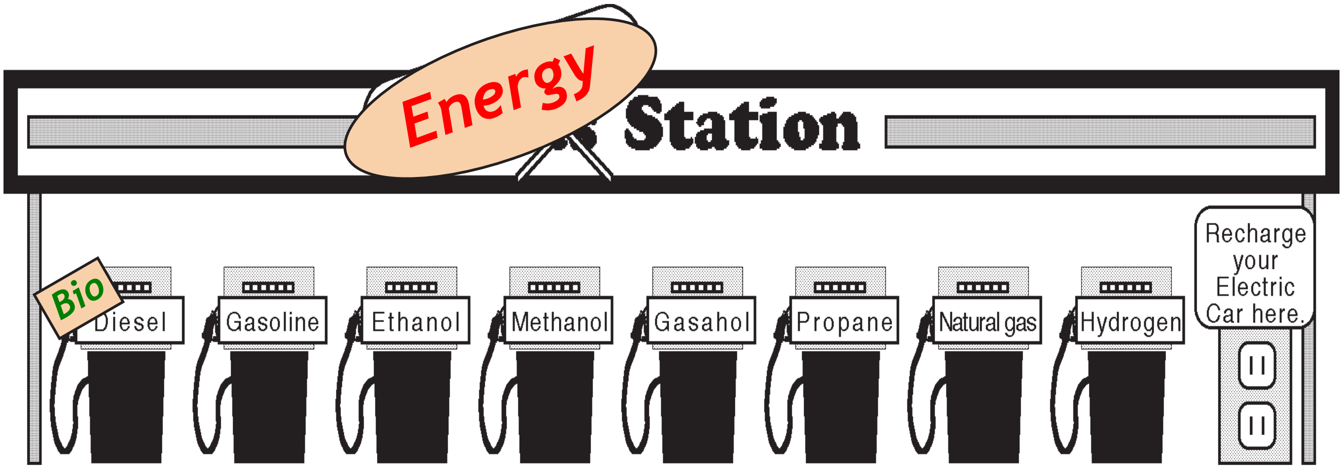
Hydrogen Fuel

There is increasing support for the use of hydrogen as a fuel for applications ranging from cars, trucks, and trains to heating air and water for buildings. Some people envision a system in which hydrogen, rather than fossil fuels, provides the most common form of energy transfer. Pound for pound, hydrogen is the most energetic of all fuels—2.5 times more powerful than gasoline. Furthermore, it is very clean-burning. Its only by-product is water.

$$2H_2 + O_2 \rightarrow 2H_2O + \text{heat}$$

Hydrogen fuel can be produced from water, in a process called ***electrolysis***. In electrolysis, electricity breaks the bonds of water molecules to produce hydrogen and oxygen gas. Regions with a source of inexpensive electrical energy—such as hydroelectric, geothermal, solar, or wind—might produce hydrogen fuel for export to regions that are energy poor. Electrolysis is described in the following equation.

$$2H_2O + \text{electrical energy} \rightarrow 2H_2 + O_2$$



The use of hydrogen as a fuel is not new. In the 1930s, German engineers, short on gasoline, used hydrogen to fuel vehicles from submarines to zeppelins. Today, hydrogen's invisible flame powers the thundering main thrusters that lift NASA Space Shuttles into orbit.

The main barriers to implementing hydrogen energy systems are (1) conversion of existing systems (vehicles and gas stations, and production facilities) to hydrogen and (2) perfecting safe storage vessels. While pound for pound hydrogen is more energetic than gasoline, it takes up considerably more volume because at room temperature it is a gas. Researchers are looking for practical ways to store hydrogen gas on vehicles.

Electric Cars

Automobile transportation has relied almost entirely on gasoline and diesel fuel throughout its history. Even now, however, fleets of electric buses are operating and it is expected that in a few years personal electric cars will not be an unusual sight on the highways.

Cars powered by electric motors and banks of storage batteries could replace conventional cars and vans. The storage batteries used for cars are a far cry from the batteries we use to light up flashlights and keep our portable CD players and cell phones running. But the principle by which they work is similar.

Currently available electric cars have top speeds of more than 70 mph and ranges of more than 100 miles. Electric cars have the following advantages:

- They are extremely quiet.
- They have very few moving parts and so have low maintenance costs. In contrast, internal combustion engines have hundreds of moving parts.
- Their range is optimal for most commuters. Battery recharging can occur overnight when electric power costs are low.
- They emit no air pollution and no carbon dioxide. The recharging process requires electricity and, of course, most electrical production pollutes. However, the conversion of energy in a fossil fuel power plant is more efficient than the conversion of energy in a car, so the use of fossil fuels would be somewhat reduced. More importantly, batteries can be charged by various nonpolluting renewable electric power sources such as solar, wind, and geothermal.

The main disadvantage of electric powered cars is their limited range. They are unsuitable for long cross-country trips. The main culprit here is the heavy weight of the batteries. As battery technology improves and battery weight is reduced, electric

vehicle range and speed will improve accordingly. Some day hydrogen-powered fuel cells may replace rechargeable batteries in electric cars, and along with a hydrogen refueling network, long-distance hydrogen powered trips would be possible.

Fuel Cells

When fuel combusts the result is exhaust and heat. Why always heat? Why not some other form of energy? Like electricity? In a battery, chemical energy is transformed to electricity and when the energy is drained, it must either be recharged or thrown away. A *fuel cell* is very much like a battery except it is not recharged or thrown away. It is ***refueled***. Although the concept goes back more than 150 years, fuel cells never were used for practical purposes until they were put into manned space craft such as the Space Shuttle.

Fuel cells can convert alcohol, natural gas, or hydrogen to electricity. Hydrogen is the most clean of all fuels for a fuel cell because it produces only water and electricity—no carbon dioxide or other pollutants.

Getting Out of the Car

People ride bicycles to go to work, to school, to shop, or just for fun. They have somewhere to go and they choose not to use fuel. The bicycle is one of the simplest and most energy-efficient means of transport. Energy-wise, a person on a bicycle is about five times more efficient than a jet aircraft and about three times more efficient than an automobile. Of course, the bicycle is quite a bit slower but, for short distances, it is an attractive option that provides healthy exercise for individuals who can use it.

Safety is one factor that affects a person's decision whether or not to use a bicycle. Many cities have systems of bicycle paths that make bicycling safer and more pleasant. The best systems have bike paths that are physically isolated from the automobile roadways.

Bicycles may not be for every person or for every trip depending on one's health. Cold and rain are also factors as bicyclists are usually exposed to the weather.

Mass Transit

In the United States, about 6% of transportation needs are met by mass transit. In Japan, the figure is closer to 47%.

Affordable cars have been available in America for decades and cities have evolved to accommodate cars. In most other developed parts of the world, cities were fully established with systems of mass transit long before affordable cars were available.

Developing cities have the opportunity to plan ahead and minimize the need for fuel-burning cars on their roads. A good example of this sort of mass transit planning is the city of Curitiba in Brazil. The inhabitants own more cars than average for Brazil, yet they consume relatively little fuel. Five express roads for buses converge on the city. Neighborhoods are linked to these express roads by local bus routes. Regulations encourage homes and businesses to locate near bus stops.

With rising concern over effects of global warming, and our growing realization that air travel makes huge contributions to CO_2 emissions, high speed trains for intercity/cross-country travel are now on the table for discussion—especially since they may easily be powered by electricity generated from renewable energy sources.

Investigation

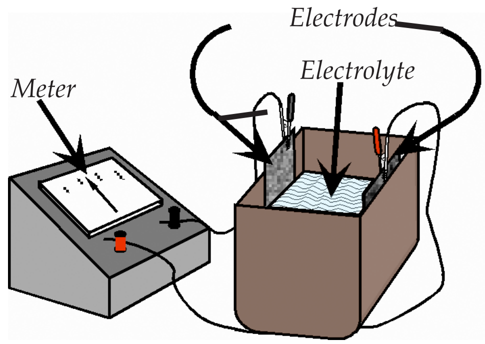
Better Batteries

You or someone you know has probably made an electrochemical cell. It can happen in your mouth if two different kinds of metal touch.

Step one: get braces or metal fillings.

Step two: accidentally get a bit of aluminum foil in your mouth.

When the two kinds of metal touch, current flows, and *oooh!* It's hard not to notice it.

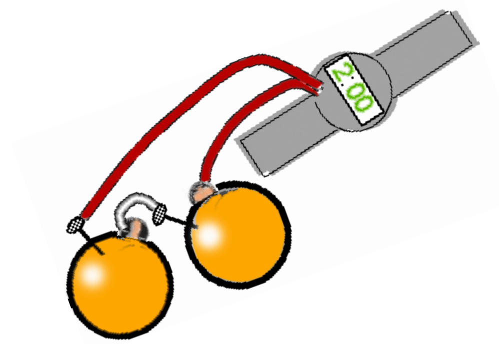


What Makes This Happen?

Each different kind of metal has a different "grip" on its electrons. When metal dissolves in water, atoms that leave the metal may pull extra electrons with them or leave electrons behind. This creates an imbalance of charge causing electricity to flow from one metal to the other.

A battery is made from several electrochemical cells. The "Holy Grail" in electric vehicle design is to develop the lightest and most efficient batteries. You can make a simple electrochemical cell using a small container, two dissimilar metals (called *electrodes*), and a liquid (called the *electrolyte*). Use a meter to measure the electrical output. Your challenge is to find out how to make the most effective cell.

Two oranges, two pennies, and some galvanized nails can create enough power to run a digital watch.



What are some of the variables you could test in experiments?

(Examples: types of metal used as electrodes, surface area of metal in contact with electrolyte)

Write a laboratory report to summarize your findings.

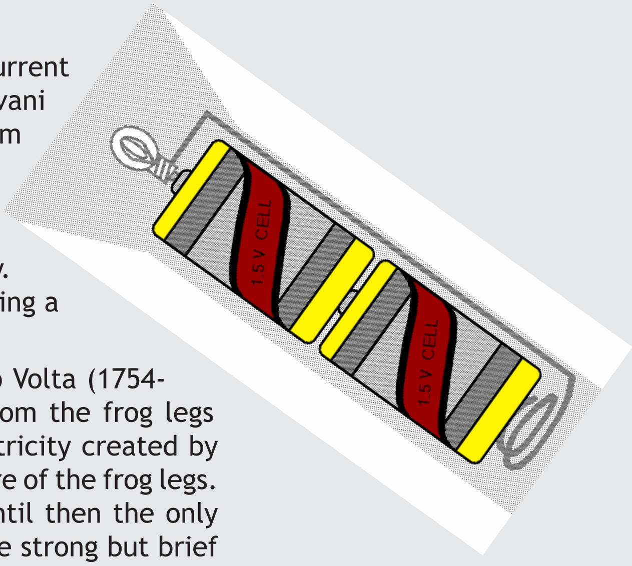
Question 9.10
Can you think of any reasons for the difference in the use of mass transit in Japan and the United States?

Conclusion

A very important part of our energy future will be linked to the choices we make about transportation. Air pollution, oil spills, and maybe even the entire climate will be affected by the kind of cars we choose to drive and how we use them. Even more profound changes in the long-term sustainability of the planet will be determined by how we work together in governments and industries to develop entirely new kinds of fuels and transport systems.

Batteries

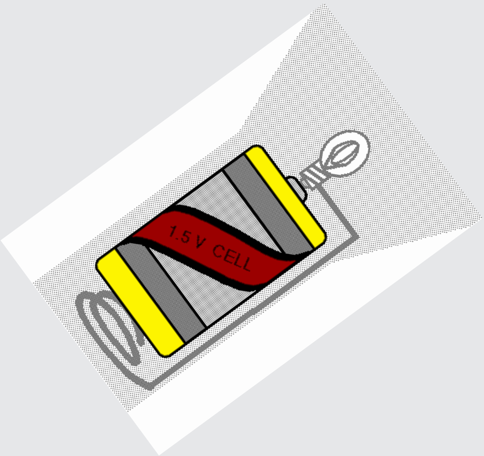
There are many ways to get electricity to flow, but two of them are the most common—batteries and generators. Small appliances such as watches, radios, and flashlights use batteries, which get energy from chemical reactions. Most high-power electric energy comes from generators that rely on mechanical movement of magnets and coils of wire.



The first device used to detect an electric current was a frog's leg. The Italian doctor Luigi Galvani (1737-1798) was studying the way sparks from static electricity made frog legs twitch. He hung the frog legs from a copper hook and touched them with an iron probe. There was no electric shock but the legs twitched anyway. He mistakenly thought the frog legs were releasing a mysterious electric force.

His friend, the Italian physicist Allessandro Volta (1754-1827), realized the electricity did not come from the frog legs alone. The frog legs were an indicator of electricity created by the iron and the copper reacting with the moisture of the frog legs. This was something new and important. Up until then the only electric currents that had been studied were the strong but brief sparks from static electricity. Through knowledge he gained from Galvani's accident with the frog legs, Volta developed a source of steady electric current. His invention, the *electrochemical cell*, is now commonly called a battery. Technically, a battery is defined as two or more electrochemical cells. However, the "batteries" you typically buy in a store are just a single cell.

We use batteries for small things that need very little power; or when we want the safety of low voltages; or when we do not want to plug our appliance into an electric outlet (cordless appliances). The development of advanced batteries is of great importance in the emergence of certain new technologies such as portable electronics, computers, electric cars, as well as storage of electric power from solar and wind energy systems.



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10. Our Energy Future

Since the discovery of fire, as early as 400,000 years ago, the development of energy technologies has made people's lives more comfortable. But the flip side of the coin has nearly always been a loss to the environment.

By 1950, world population had passed the three billion mark. By the end of 1999 it reached six billion. Projections for the world population by the year 2050 range from seven billion to 11 billion people. If our approach to using energy does not change, use of the world's resources will not just keep pace with the growing population—it will occur at an ever-increasing rate as developing countries adopt the energy-rich life-style of industrialized nations.

You have already seen several energy technologies that are alternatives to fossil fuels—from passive solar heating in homes to hydrogen-powered automobiles. Let's look at two radically new technologies for using energy, and then the social, political, and personal changes needed for long-term survival on Planet Earth.

***Nuclear fusion** takes place on the Sun continuously, producing tremendous amounts of energy as hydrogen is converted to helium. Could nuclear fusion supply our energy needs on the Earth?*

Power from Nuclear Fusion

Energy experts refer to fossil fuels, hydroelectric power, and wind power as "primary sources" of energy. However, that is not strictly true—the energy in these sources comes from the Sun. Like the rest of the universe, the Sun obeys the law of conservation of energy. It does not create energy. The Sun converts energy from one form to another. The light and heat we receive from the Sun comes from energy released from the nuclei of hydrogen atoms through a process called *nuclear fusion*.

A proton in an atom's nucleus has a positive electric charge and, since like charges repel each other, we would expect protons to push away from each other. But the protons inside a nucleus do not push each other away because an entirely different kind of force holds the protons together. The force acts only at the very short distances inside the nucleus of an atom, and is much stronger than the electric force. We call it *the strong force*.

The Sun is composed almost entirely of hydrogen. Hydrogen is the simplest of all atoms. At room temperature it consists of a nucleus with one proton surrounded by a single electron. The interior of the Sun is extremely hot—millions of degrees Celsius. At that temperature, the hydrogen's electrons are stripped away and hydrogen nuclei (protons) encounter each other at very high speeds. If two protons hit each other hard enough, the strong force takes over, and the two protons stick together. What happens next is somewhat complicated, involving a total of four protons. The end result of this fusion process is a stable nucleus of helium (with two protons in the nucleus) and the release of energy.

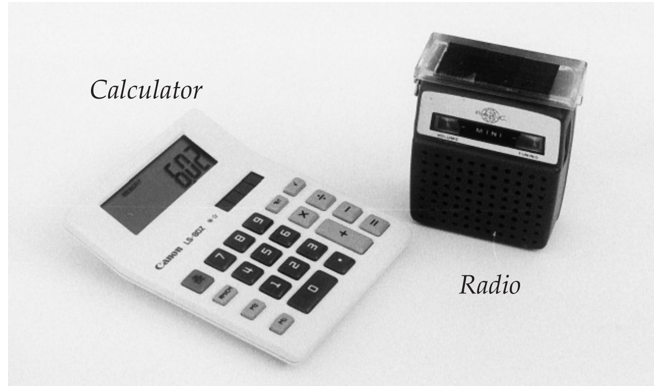
On Earth, scientists have tried to start a fusion reaction. In the case of the hydrogen bomb, they succeeded. But large nuclear explosions are not very helpful in generating energy for human use. What is needed is a controlled fusion reaction that changes very small amounts of hydrogen into helium, and produces energy at a continuous rate. Active fusion research projects have been underway in the United States, Europe, and the former Soviet Union for the past 40 years. Scientists from these countries currently work together, sharing information and ideas.

To achieve fusion the material must be heated to over 100 million degrees Celsius. At that temperature, material becomes *plasma*, a gas-like mixture of electrons and protons like the interior of the Sun. The problem is how to contain this hot plasma. If it touches any container, it cools down to temperatures too low for fusion to occur. Since plasma is made from electrically charged particles it can be confined by magnetic forces. Another approach is to form the plasma starting from a solid pellet of frozen deuterium, a form of hydrogen, and heating the pellet by firing super-powerful lasers at it. Both methods require a great deal of energy.

In 1991, researchers at the CERN high energy physics laboratory in Switzerland announced a "break-even" condition of nuclear fusion. This means the energy that came out of their fusion experiment was as great as the energy put into it. This was a momentous breakthrough, but by the end of the decade a process for producing energy from fusion still had not been developed. More breakthroughs will be necessary before fusion power becomes a viable source of energy.

Power from Solar Cells

Solar cells, also called *photovoltaic cells*, were developed for the space program as a way of converting sunlight directly into electrical energy. In a solar cell, light is absorbed by a material called a *semiconductor*, usually silicon with special impurities in it. When sunlight falls on this material the light energy is turned into electrical energy. Almost all spacecraft, except those destined for the outer reaches of the solar system, are equipped with solar cells for electricity.



Where are the photovoltaic cells on these devices?

When solar cells are generating electricity, there is no pollution. There is nothing to wear out from moving parts, only aging of the semiconductor material. You have probably seen the solar cells that power calculators or watches. They also supply electricity in locations remote from utility company power lines for things such as ocean buoys, rural homes, and highway call boxes.

The solar cell on a calculator is about the size of a postage stamp. To supply all the needs of a typical U.S. household, it would require a 20 foot by 20 foot array of cells. That probably would fit on top of a single family home, the size of an array needed for a multi-story apartment building would be too large for the roof.

The cost of electricity from solar cells has been falling as newer cells are more efficient for less money. There will probably be a time when electricity from solar cells can compete with other sources. In remote locations without access to power lines, it is already a cost-effective choice.

As with all forms of solar power, the electrical energy must be stored for use when the Sun is not shining. Solar cells can charge batteries when the Sun is shining, or they can power electrolysis to produce hydrogen fuel from water.

Question 10.1
What are the differences in the impact on global systems between centralized and decentralized power production?

Question 10.2
What are the differences in the impact on human society?

Question 10.3
How easy is it to categorize other energy sources as centralized or decentralized?

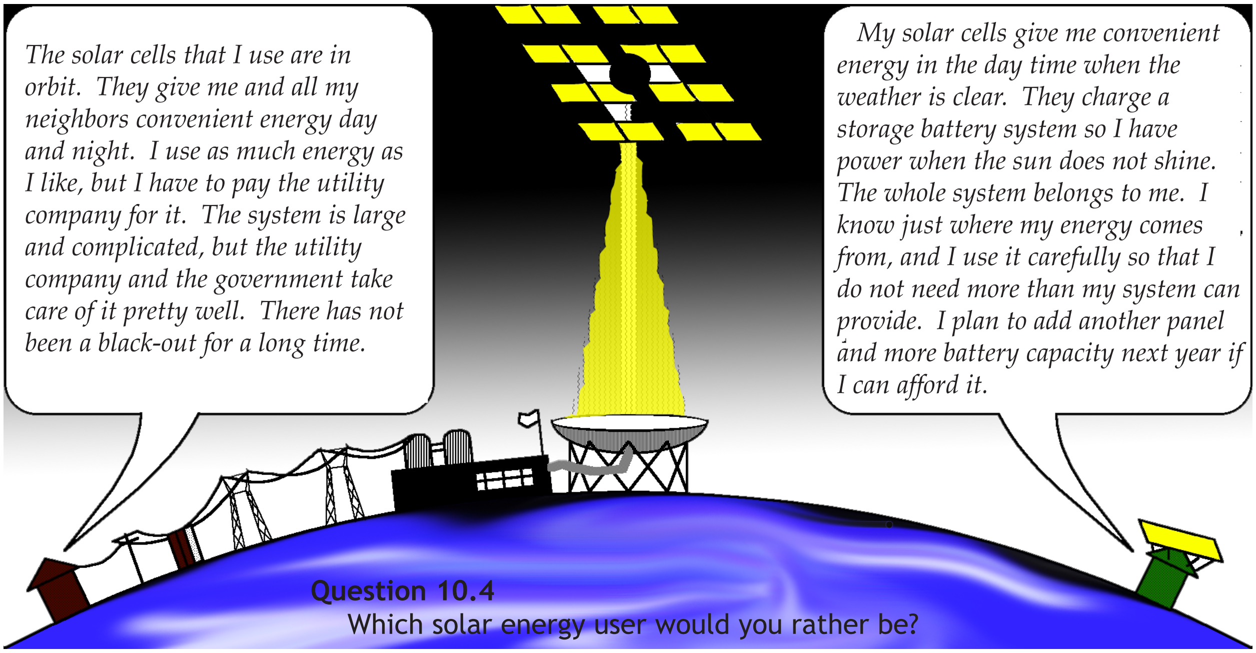
Bigger Sources or More Sources?

The two power sources just described both exist because of government research. Fusion power will take more research dollars if it is ever to be viable; and even though solar cells have expanded far beyond the space program, government money has helped (and will probably continue to help) to make solar cells more efficient at lower cost.

Fusion technology and solar cell technology have a difference that highlights one of the choices energy users must make as we move into the future. The choice is one of scale. A fusion power plant might be similar to current electric power plants—a massive cooperative effort among a whole nation of energy users. Once completed, the fusion plant's power would be available far and wide to everyone on the power grid—a *centralized* power source. In contrast, small solar cell arrays can be placed right next to the place where the energy is needed, or even built into the device, so that no energy is lost in long-distance transmission—a *decentralized* power source.

Investigation

Energy from Sunshine



Question 10.4
Which solar energy user would you rather be?

Question 10.5
Which situation is closer to the way you use energy now?

Question 10.6
What can you add to the remarks by the two energy users?

In the realm between science fact and fantasy are ideas that would reverse the roles of fusion and solar cell technology. In 1991, researchers from the University of Utah claimed to have released energy from the fusion of hydrogen atoms in a simple tabletop apparatus. It seemed a dream come true. Energy would become inexpensive and environmentally benign and virtually unlimited. It was on all the front pages. The U.S. Congress scheduled hearings to explore impacts of this breakthrough. Unfortunately, the experiments could not be replicated, and the promise of a small fusion reactor we could install in our garage remains elusive.

Other scientists have proposed using solar cells to create large centralized power plants. One of the boldest ideas is to assemble vast arrays of solar cells in orbit and convert the electricity into microwave beams for transmission to giant receiving stations on Earth.

The Future Is Now

Eco-San Francisco illustration by Richard Register of Ecocity Builders, California. http://www.ecocitybuilders.org

Recent history contains several examples of revolutions in the way humans use energy. The development of the steam engine around 200 years ago ushered in the age of fossil fuels. The distribution of electricity 100 years ago abruptly changed our energy habits, as did the rise of the automobile shortly afterwards. Less than half a century ago nuclear power entered the field as an entirely new source of energy.

Many people believe we are poised at the brink of another revolution. Articles in newspapers and magazines keep popping up about some technology or other—alternative fuels, superconductors, new fuel cells, cold fusion, hot fusion—some breakthrough that will be our energy salvation. It seems something big ought to be happening, but it just isn't.

Our automobile-centered culture has resulted in sprawling, very inefficient cities. People's commute times have increased and degraded their quality of life. Is it possible for us to embark on a path of redesigning cities that are intrinsically more efficient? Can we have cities where systems of business, goods, services, and entertainment are designed so people do not need cars as much?

Maybe the biggest thing that *is* happening is a growing awareness. We see the impact of energy use on the health of humans who breathe city smog. We measure the increased acid content of rainfall—acid that comes from compounds billowing from our electric power plants and motor vehicles. We are getting a clearer picture of the entire global system. As our use of energy puts more and more carbon dioxide into the air, scientists work to predict its effects on the global climate. And as reserves of fossil fuels get lower, they will become more expensive. Whether there is a big breakthrough or not, something needs to change.

Recently, 74% of the respondents to a poll of American voters agreed the government should provide federal support, such as tax incentives, to expand development and use of energy-efficient and renewable-energy technologies. There is hope that government, industry, and the general population may cooperate to tackle the energy problem. There are a thousand small solutions that can make a big difference. They could "buy time" until one big technological breakthrough is achieved, or maybe each little improvement is part of the breakthrough.

Improving energy efficiency, developing alternative fuels, improving and using public transportation, installing thermal insulation, recycling materials such as aluminum, cutting waste from daily energy-use habits—all these things can be part of a solution. We know they work because we are already doing them. Some of the groundwork is already laid. What happens now depends on the next generation of leaders from the industrialized nations. It depends on *you*.

Investigation

Payback Time

It is sometimes difficult for individuals to realize that when it comes to conservation, every little bit makes a difference. If a person is making a good salary, it does not seem urgent to install a solar water heater in order to save on energy bills. When buying a new home, it's not very appealing to pay thousands of dollars more for extra insulation or double-paned windows, so as to save money on energy in later years. "Sure, it will pay off in two or three years, but I need the money now!"

Let's say you just bought your first house. After moving in you discover your heating and cooling bill averages about $150 per month, which you think is too high. You install double-paned windows and insulate the ceilings and walls. It costs you $2,000 for these improvements.

Your next energy bill arrives—it's $50. Let's assume you average bill is now $50 a month and you know you are going to stay in your house for at least five years.

- What is your payback time?
- How much money do you save while you live in your house?
- Do you think you've added value to the house?
- Now assume your original average bill was $100 per month instead of $150 per month. Answer the above three questions again using this information.

Real Results - Now!

Remember Mary Ann Piette, she is one of many scientists and engineers who specialize in the use of energy. She recently conducted a study of how to improve energy efficiency at 28 public buildings. One of them was Edgerton Elementary School in Kalispell, Montana, where, as part of the study, the following improvements were made. Roof insulation was increased from R-11 to R-38. Wall insulation was increased from R-11 to R-19. Single pane windows with an R-1 rating were replaced by double paned windows with an R-3 rating. Additionally, the foundation was extended above the floor and earth was piled against it outside to provide further insulation. Energy efficient fluorescent light fixtures were installed. The air conditioning systems were improved. The yearly energy needs for the building were reduced from 114 kilowatt-hours per square foot of building to 14 kilowatt-hours per square foot, **saving the school district thousands of dollars in energy costs each year.**

The energy use in one school was cut to less than one eighth of what it had been by using a little bit of new technology, a little bit of ancient technology, and a lot of practical sense in the use of insulating materials that are commonly available. If all energy use were reduced that much think of how that would affect air pollution, the number of oil spills, and global climate change.

It worked in Kalispell, Montana. Can it work worldwide and into the future?

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/9eu.html. We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

Investigation

Your Vote on Energy Measures

Most laws are made to promote the well-being of the country's citizens, but in practice, it is not that simple. Legislators and voters must ask, "Whose well-being are we looking out for, and what is the best way to accomplish our goals?" There are often conflicting viewpoints. One course of action may benefit some groups, but harm others. Another may be costly in the short term, but save money in the long term.

Select two of the following legislative proposals to write about—one you would support, and one you would not. Use the information in this book, other sources, and your own opinions to justify your point of view. Write an outline, discuss your ideas with other students, and then write an essay on the two proposals. Identify the goal of each proposal, who benefits and who pays the costs associated with the proposal. Try to convince your classmates that your decision on each proposal is right and fair.

Proposal 1: Conservation Tax Credit

This measure offers a tax credit for purchases of energy-efficient products. Individuals will be reimbursed half of their expenses for home insulation, energy-efficient lighting, and refrigerators. Businesses will be reimbursed half of their expenses for improvements that reduce their overall energy use. Money will come from the general tax fund.

Proposal 2: Energy Sales Tax

A sales tax of 100% will be added to the cost of all fossil fuels. Energy prices will double. All funds raised will be used to improve public health and the environment. Utilities will be allowed to raise rates to cover this cost.

Proposal 3: Incentives for Industry

Building contractors, factories, and private utility companies will not have to pay taxes on half of their profits from the sale of energy-efficient products such as solar house and water heating, solar and wind power systems, and vehicles that run on alcohol, hydrogen, or electricity.

Proposal 4: Encourage Recycling

Manufacturers of all products will be required to develop a system to recycle all wastes, including packaging materials of consumer goods. In order to be approved, proposals must be energy-efficient and environmentally safe.

Proposal 5: Require Energy Efficient Cars

All cars must inspected to see that they get at least 30 miles per gallon. Cars that do not comply will be kept off the road.

Proposal 6: Fee-Rebate Plan for New-Car Fuel Efficiency

Buyers of fuel-inefficient cars would pay a fee of $200 for each mile per gallon the vehicle gets less than 30 miles per gallon. Example: someone who buys a car that gets 29 miles per gallon would pay an extra $200. If the car gets 25 miles per gallon the person pays an extra $1,000. The money collected would be used as rebates to buyers of fuel-efficient cars at the rate of $200 for each mile per gallon the vehicle gets greater than 30 mi per gallon.

Resources

American Council for an Energy-Efficient Economy (ACEEE) Web site: http://aceee.org/

California Energy Commission
Web site: http://www.energy.ca.gov/

Center for Renewable Energy and Sustainable Technology (CREST)
Web site: http://solstice.crest.org/index.shtml

Energy Efficiency and Renewable Energy Network (EREN)—DOE Office of Energy Efficiency and Renewable Energy. Web site: http://www.eren.doe.gov

Natural Resources Defense Council (NRDC),
Web site: http://www.nrdc.org/

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